Ionospheric Mapping Using Ground-Based GPS Receivers in Alaska

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Effects of Space Weather on GPS

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❖ Technology
❖ Applications
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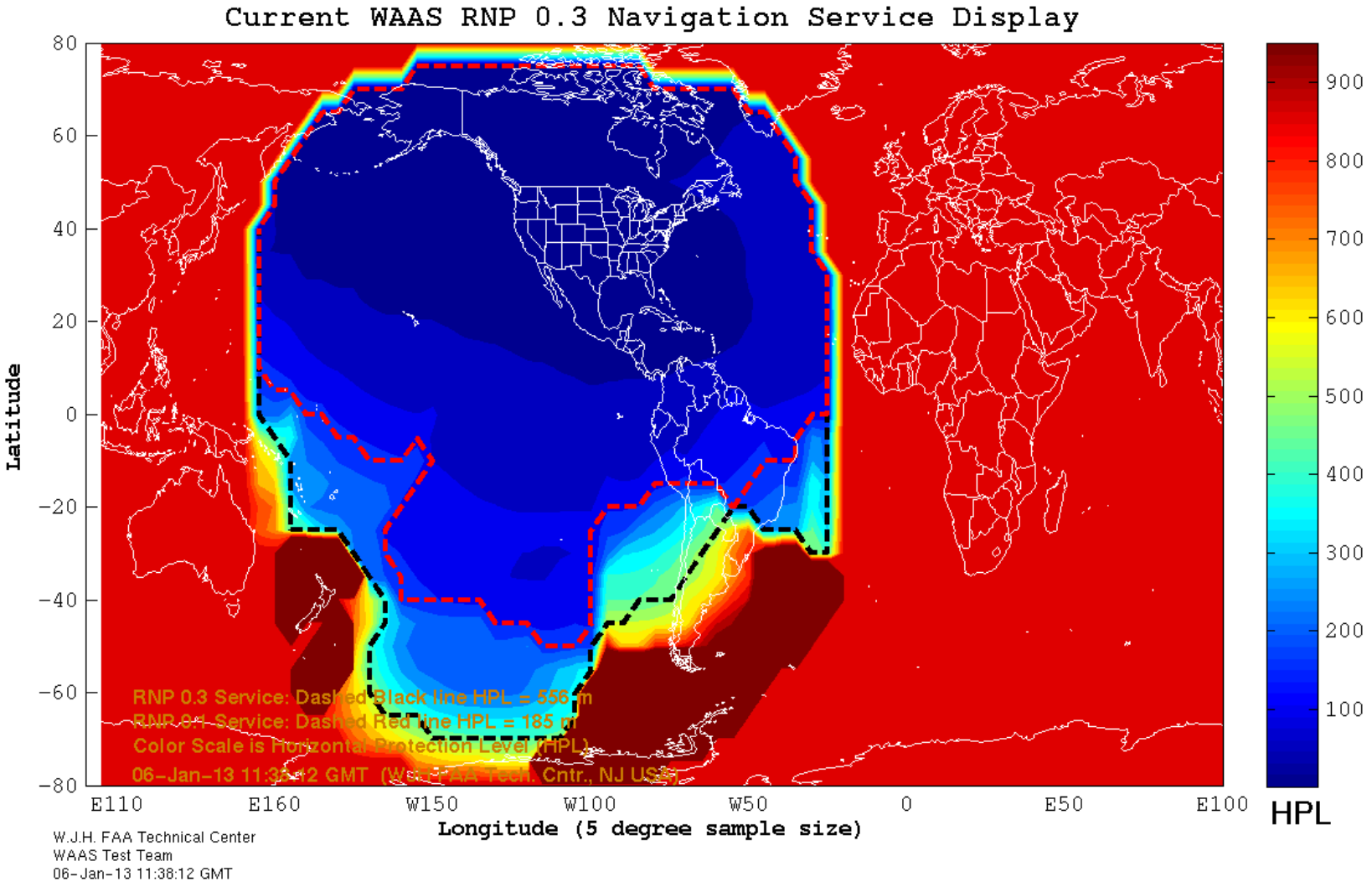

Horizontal Protection Level (HPL): radius of a circle in the horizontal plane (the plane tangent to the WGS-84 ellipsoid), with its center being at the true position, which describes the region that is assured to contain the indicated horizontal position. It is based upon the error estimates provided by WAAS.

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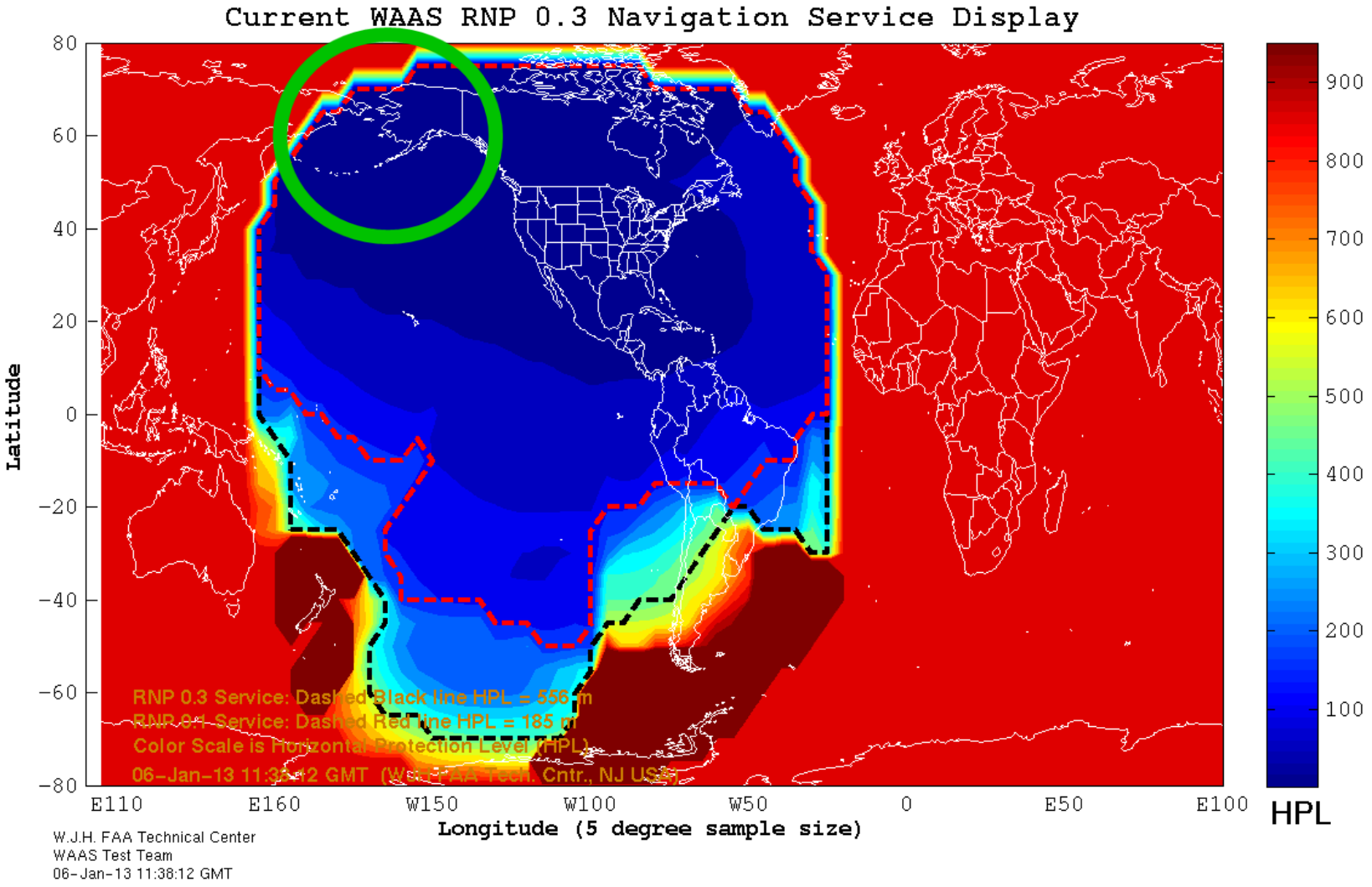

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WAAS Reference Receiver at Fairbanks, AK

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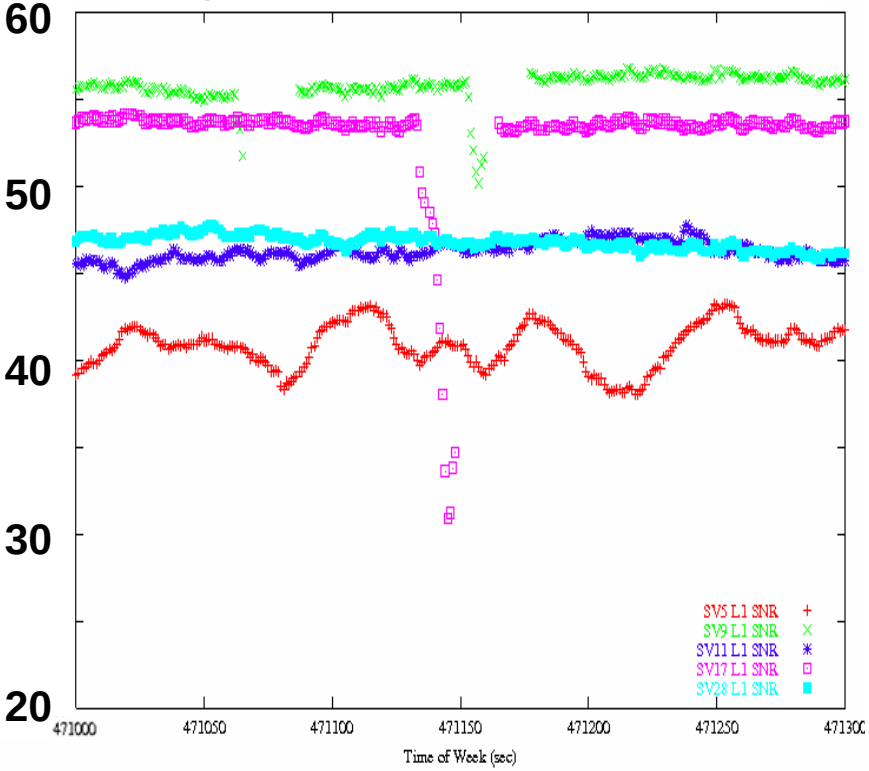
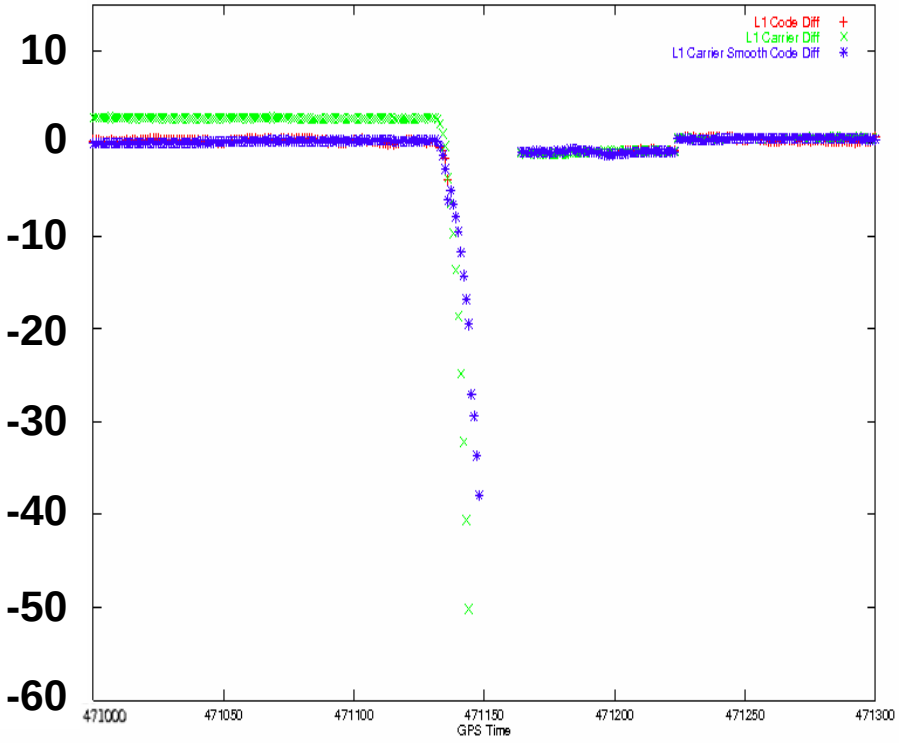
DR#52: Ionospheric Scintillation caused High Position Errors at Fairbanks
GPS Week/Day: Week 1420 Day 5 (March 30, 2007)

Discussion: On March 30, 2007 (GPS Week 1420 Day 5), large vertical position errors (VPE) were observed at Fairbanks WAAS reference receiver thread A (WRE-A).

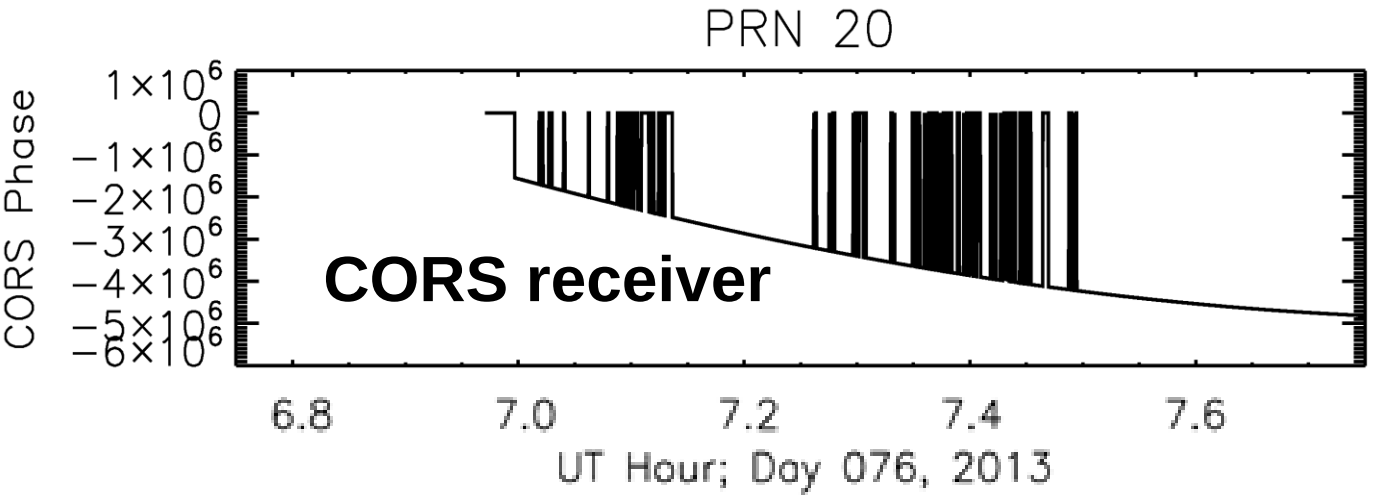
Signal to Noise Ratio (dB)



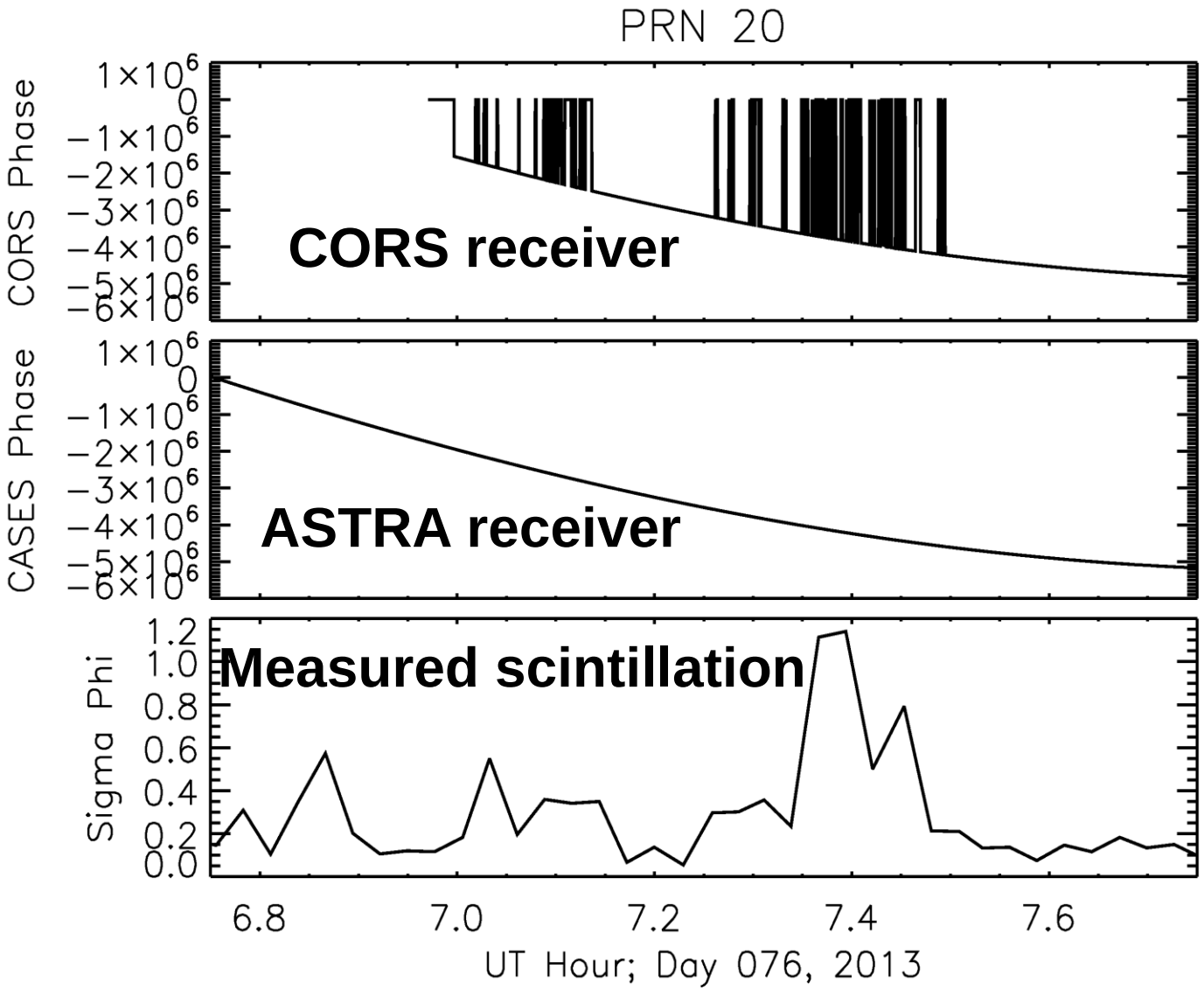
Error (m)



Scintillation of GPS signals can disrupt critical services



Scintillation of GPS signals can disrupt critical services

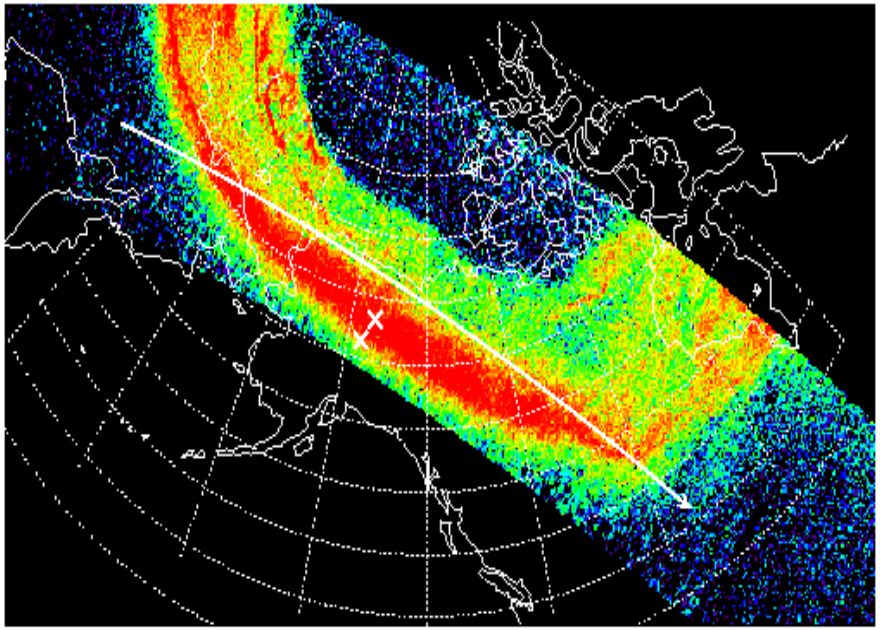


MOTIVATION

- **Amplitude and phase scintillation can cause serious difficulties for GPS receivers.**
- **Goal: understand occurrence & severity of scintillation, and develop a predictive model**
- **Need: to improve the temporal and spatial resolution of ionospheric remote sensing in a region of poor coverage but of high geophysical interest.**
- **Six GPS receivers (ASTRA CASES model SM-211) were deployed in Alaska, for the purpose of documenting and understanding GPS scintillation at high latitudes, and to study the effects on operational GPS-dependent systems**

CASES ALASKA CHAIN

- **Array of CASES GPS receivers deployed in Alaska**
  - **Kaktovik (70.1° N, 143.6° W)**
  - **Toolik (68.6° N, 149.6° W)**
  - **Fort Yukon (66.6° N, 145.2° W)**
  - **Poker Flat (65.1° N, 147.4° W)**
  - **Eagle (64.8° N, 141.2° W)**
  - **Gakona (62.4° N, 145.2° W).**



CASES GPS Receiver

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- **Remote re-programmability**
- **Full control of receiver behavior, products, and cadences**
- **Superior performance in scintillation Standalone system**
- **Cost-effective space weather instrument**
- **Made in the US**

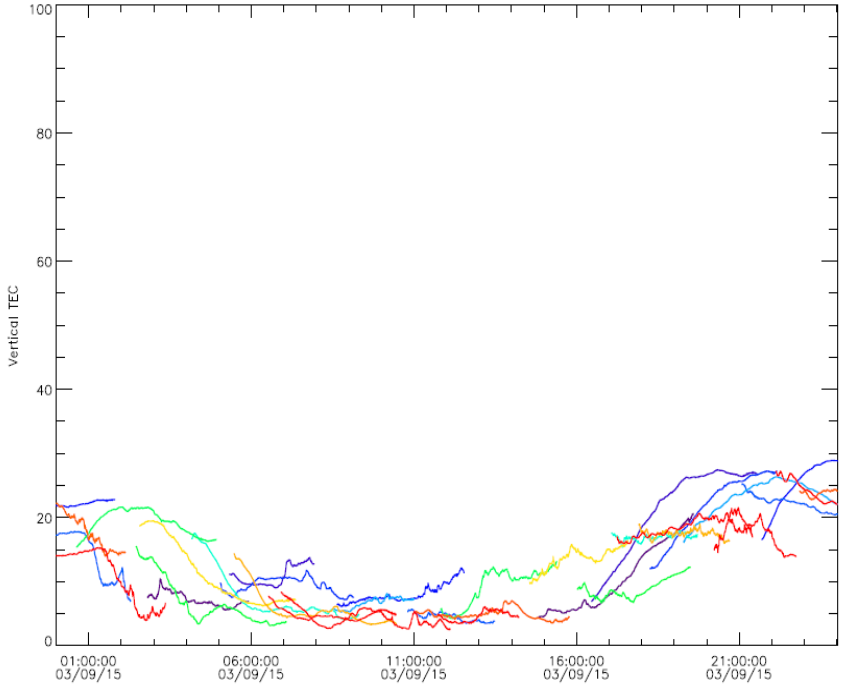
Dual frequency (L1 and L2C) CASES GPS Receiver

Connected Autonomous Space Environment Sensor

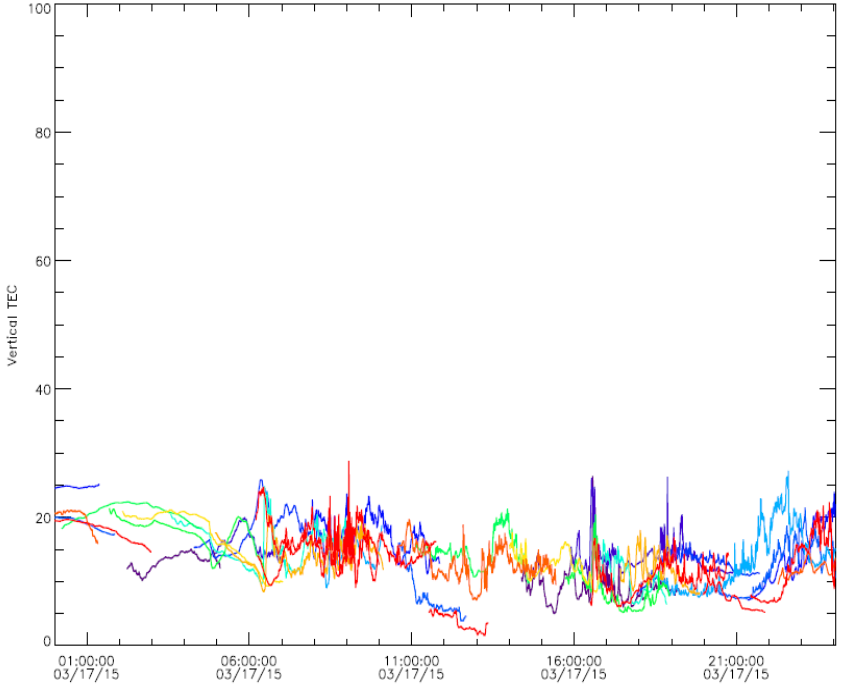
Data Type	Per Channel High Rate Data	Per Channel Low Rate Data	Per Channel Scint Params	Other
Default Data Rate	**100 Hz**	**1 Second**	**60 Seconds**	**1 Second**
Configurable Rate?	Yes, 50 or 100 Hz	Yes, >= 1 Second	Yes	Yes, >= 1 Second
Available Parameters	• Integrated Carrier Phase • In-Phase Accumulation • Quadrature Accumulation • GPS Time • Receiver Time	• Pseudorange-based **TEC** • Phase-based delta **TEC** • Pseudorange • Integrated Carrier Phase • GPS Time, Receiver Time • Doppler Frequency • SV Elevation, SV Azimuth • C/N0 • Data Validity Flag, Cycle Slip Flag • Signal Acquisition Status • PRN, SV Health	• S_4 • σ_φ • τ_o • Scint Power Ratio • GPS Time • Reference Channel Status • PRN	• Receiver X/Y/Z Position • Receiver X/Y/Z GPS Time • Receiver Time • Velocity • Receiver Clock Error • Receiver Clock Error Rate • Nav Solution Flag

Total Electron Content (TEC)

TEC: March 9, 2015

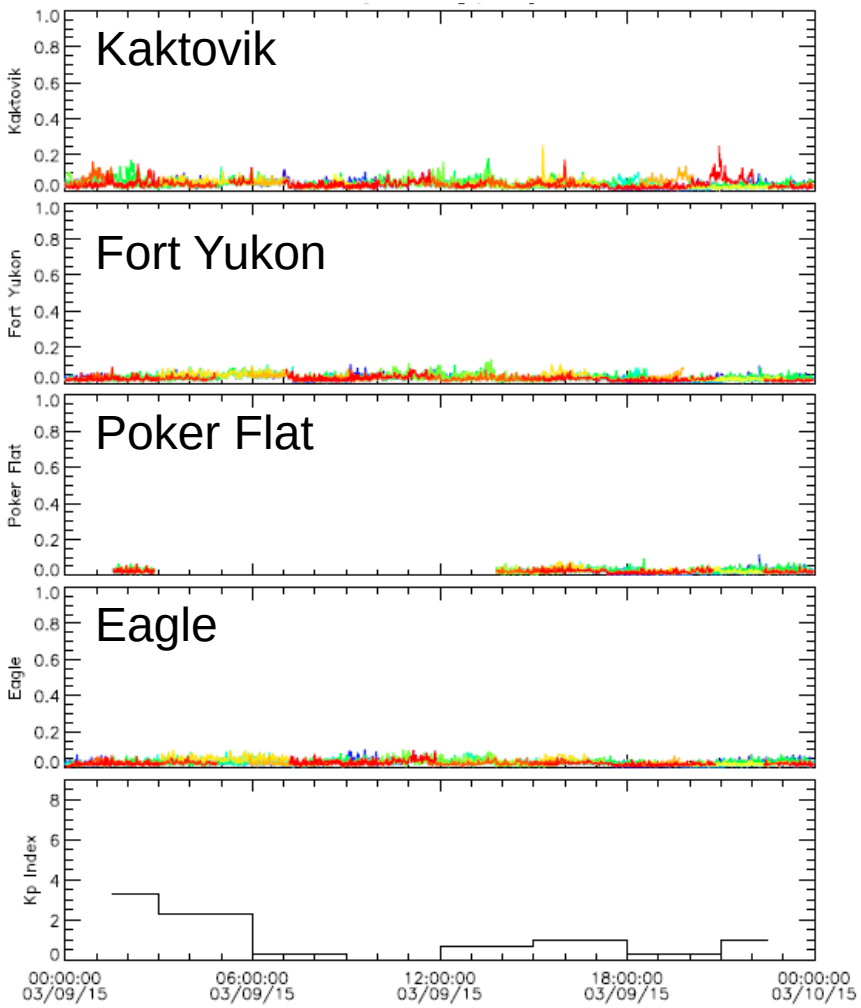


TEC: March 17, 2015

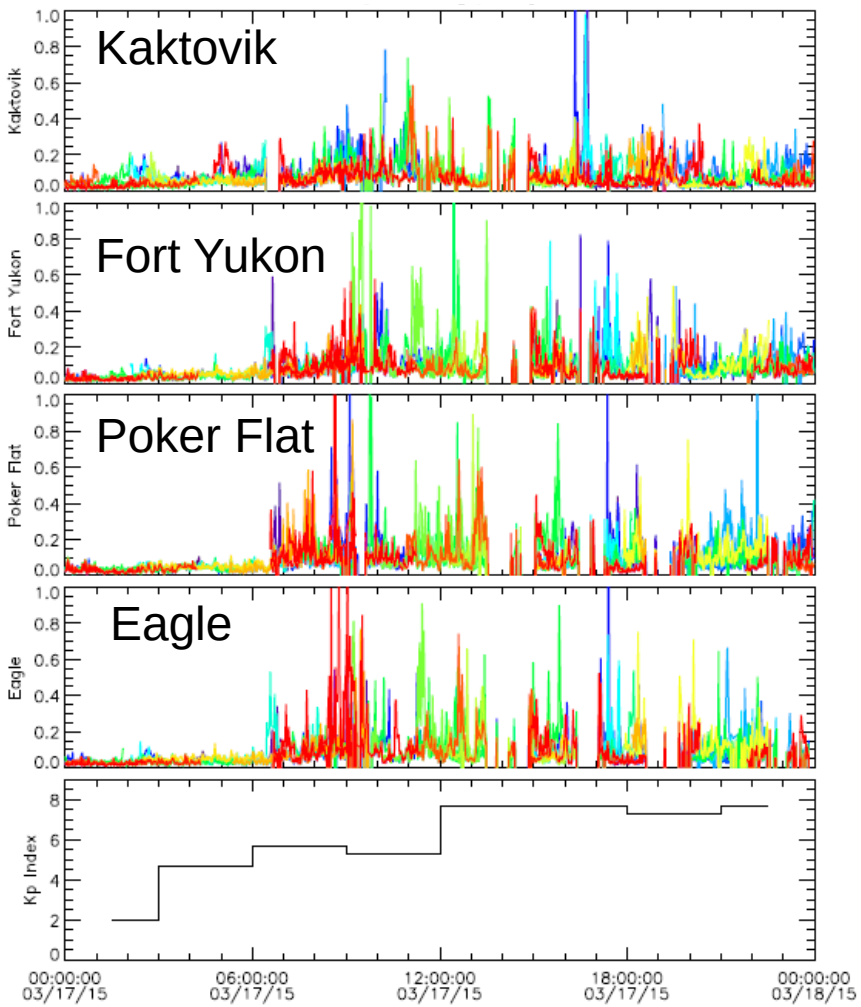


Phase Scintillation

March 9, 2015



March 17, 2015



Phase Scintillation

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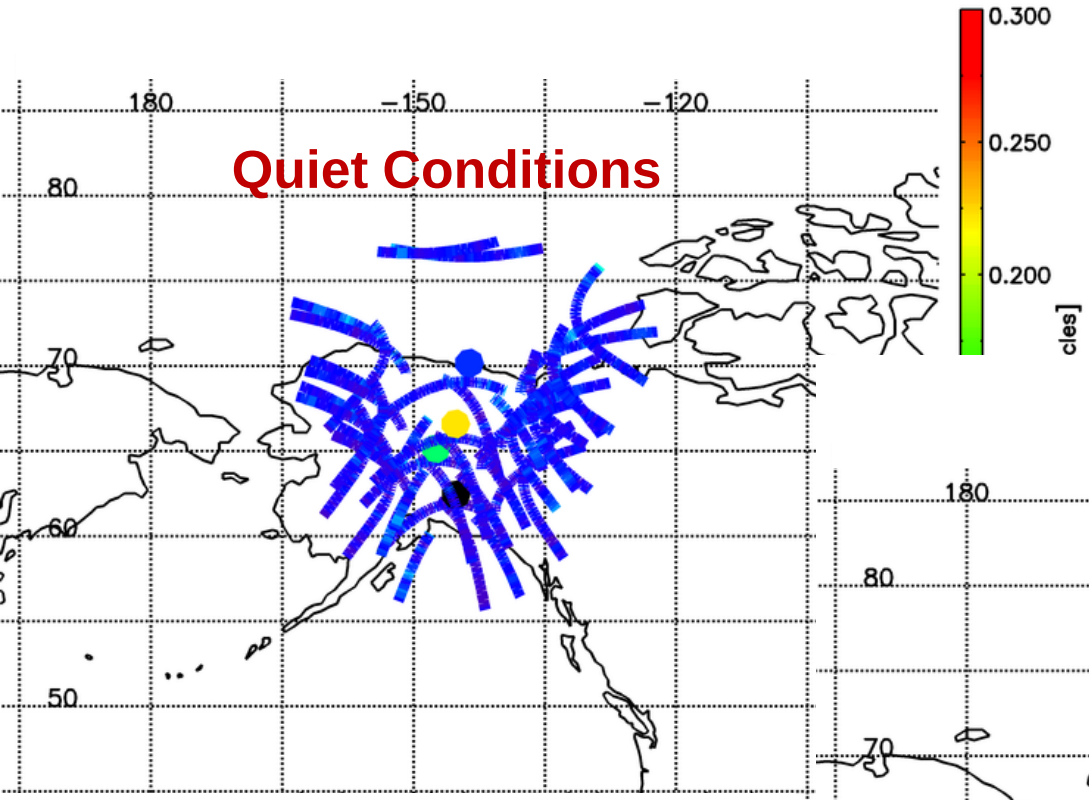
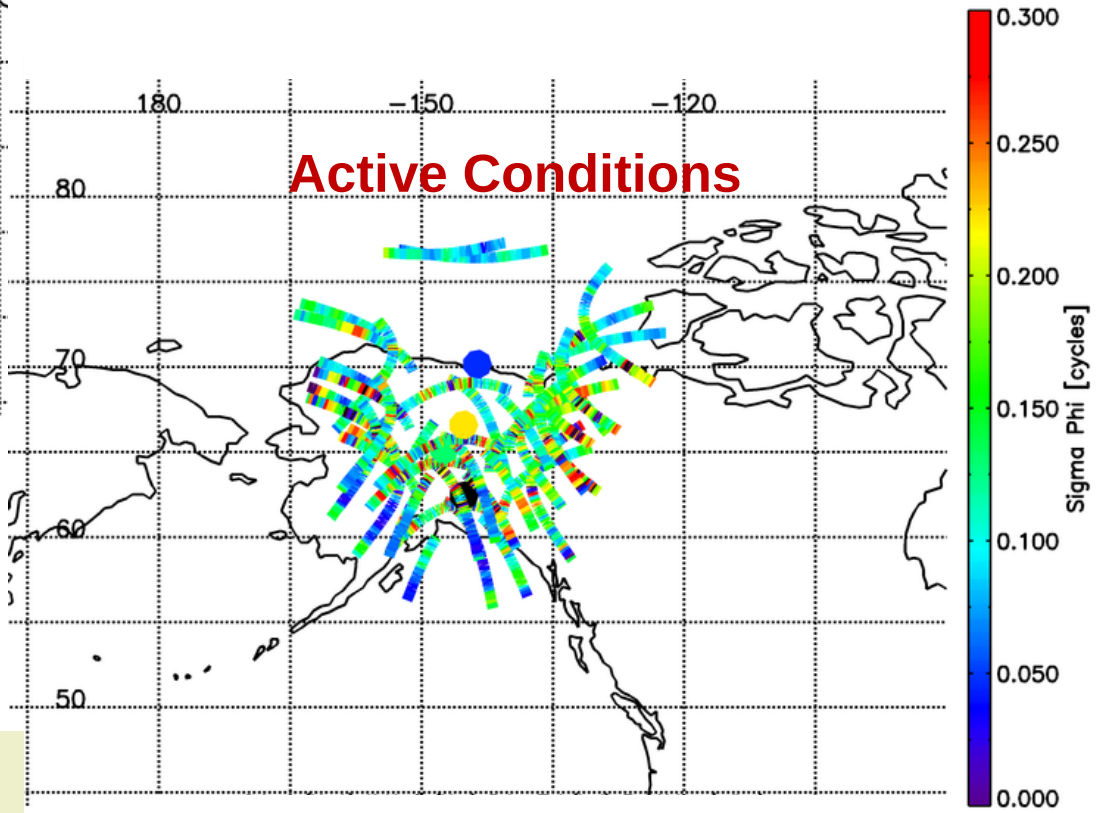


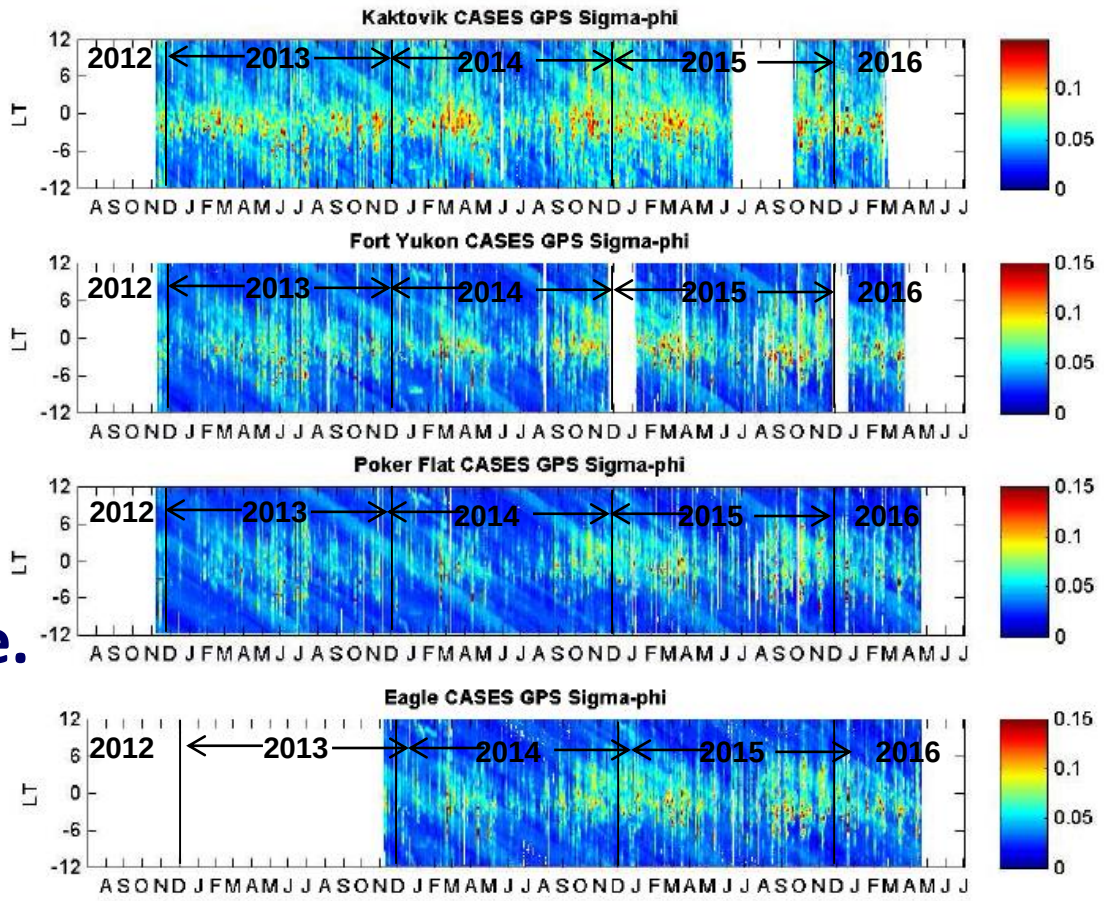


http://cases.astraspace.net

Climatology

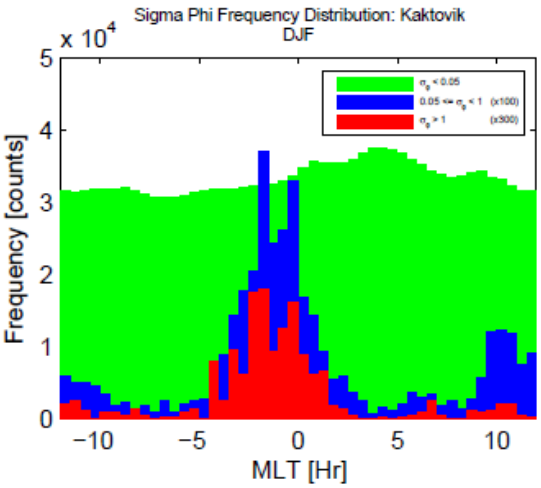
- Bin data into 10-min segments for each day of observations
- Elevation mask of 20°

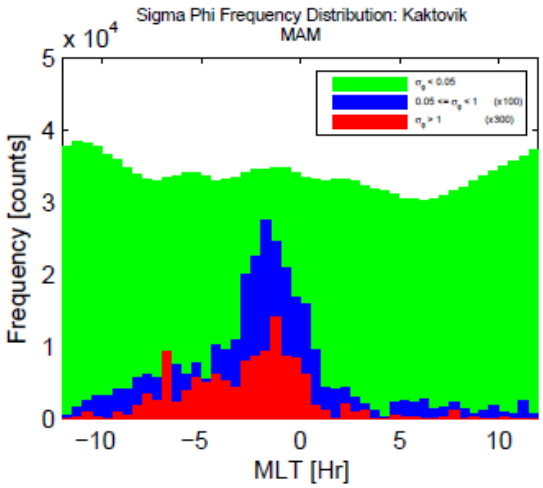
1. Severity of phase scintillation decreases with decreasing latitude.
2. Largest phase scintillations occur near magnetic midnight.

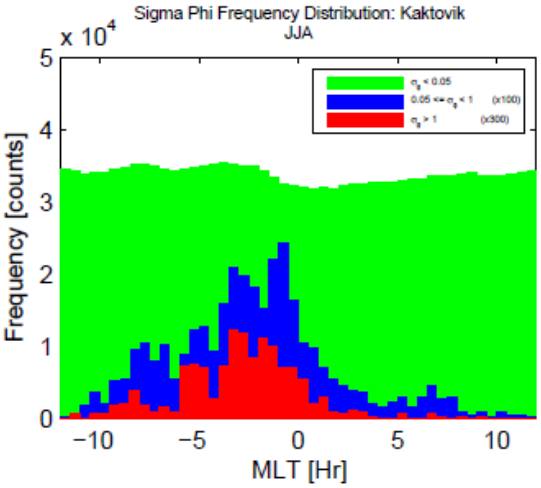


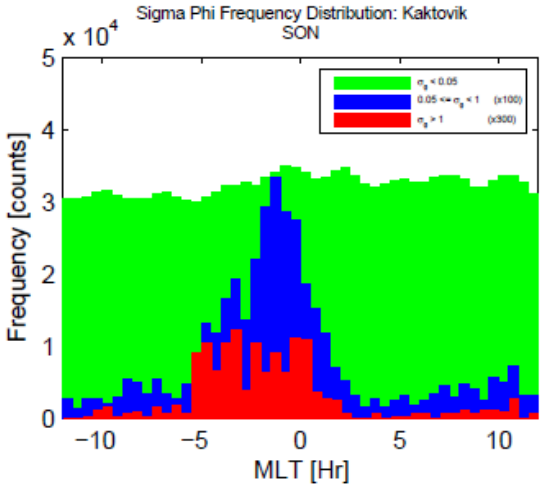
Occurrence Statistics

- Previous studies have suggested that GPS phase scintillations are largest in the nightside auroral oval [*Prikryl et al*., 2011].
- The Alaska data show a similar result, with a preference for evening hours up to about 6 hrs before midnight.
- Distribution has a seasonal dependence









Multi-Instrument Dataset

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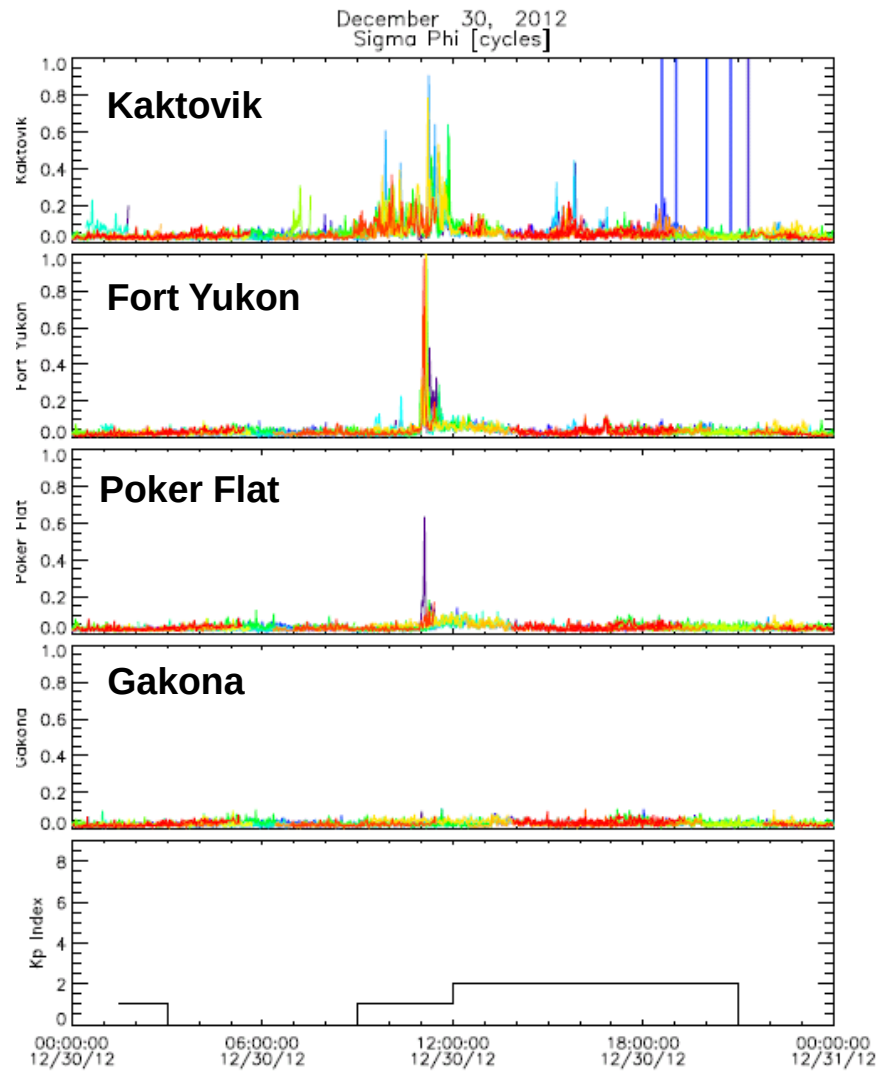
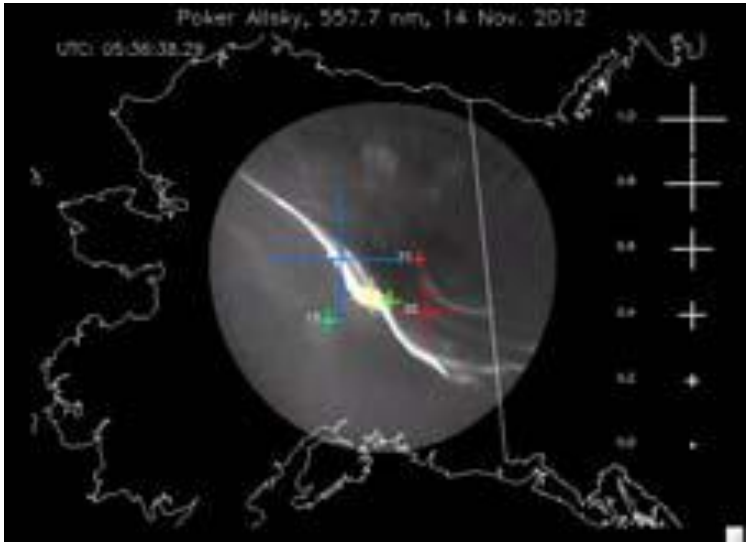
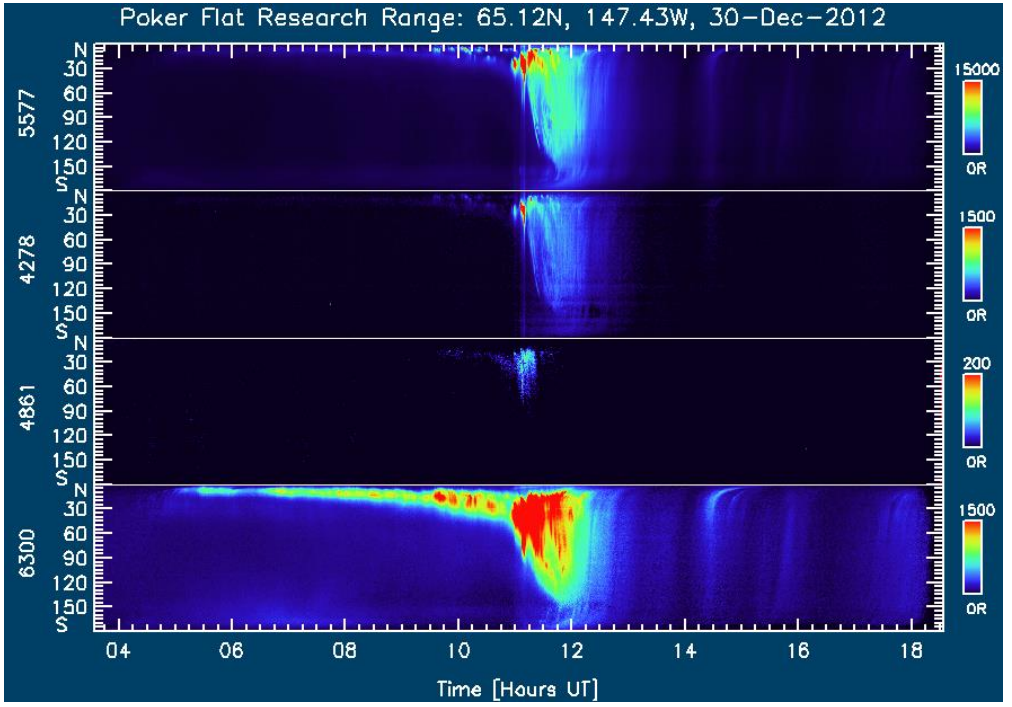
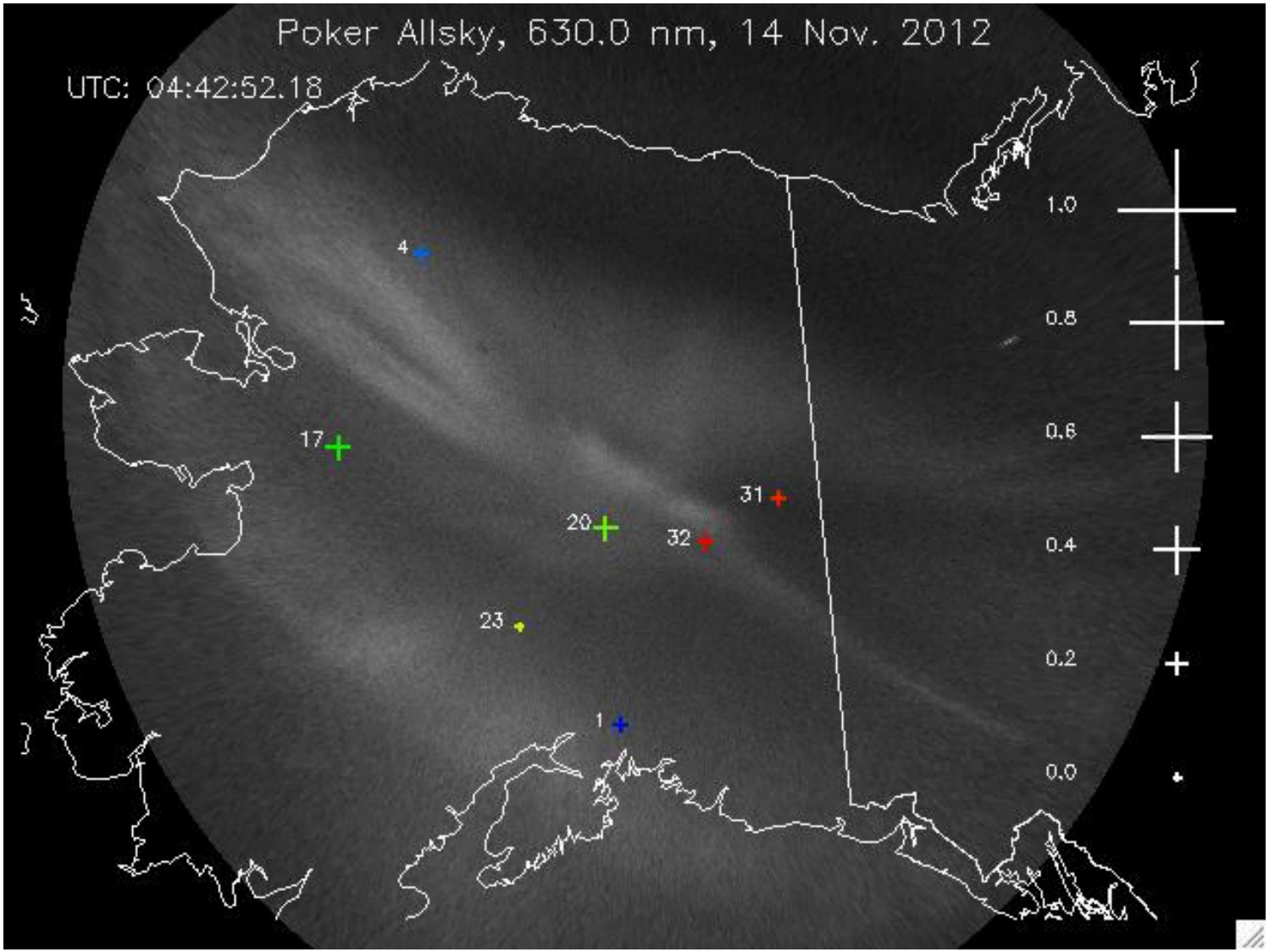
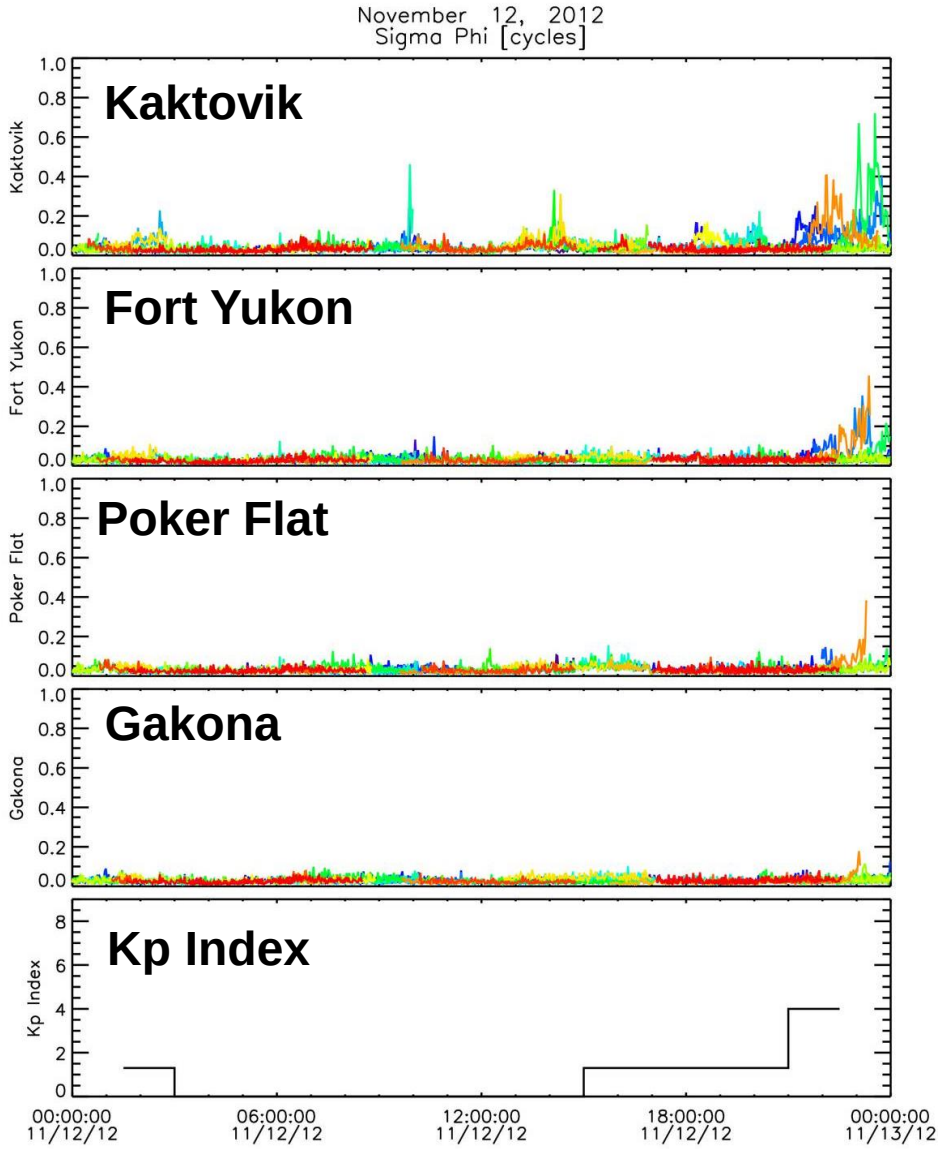






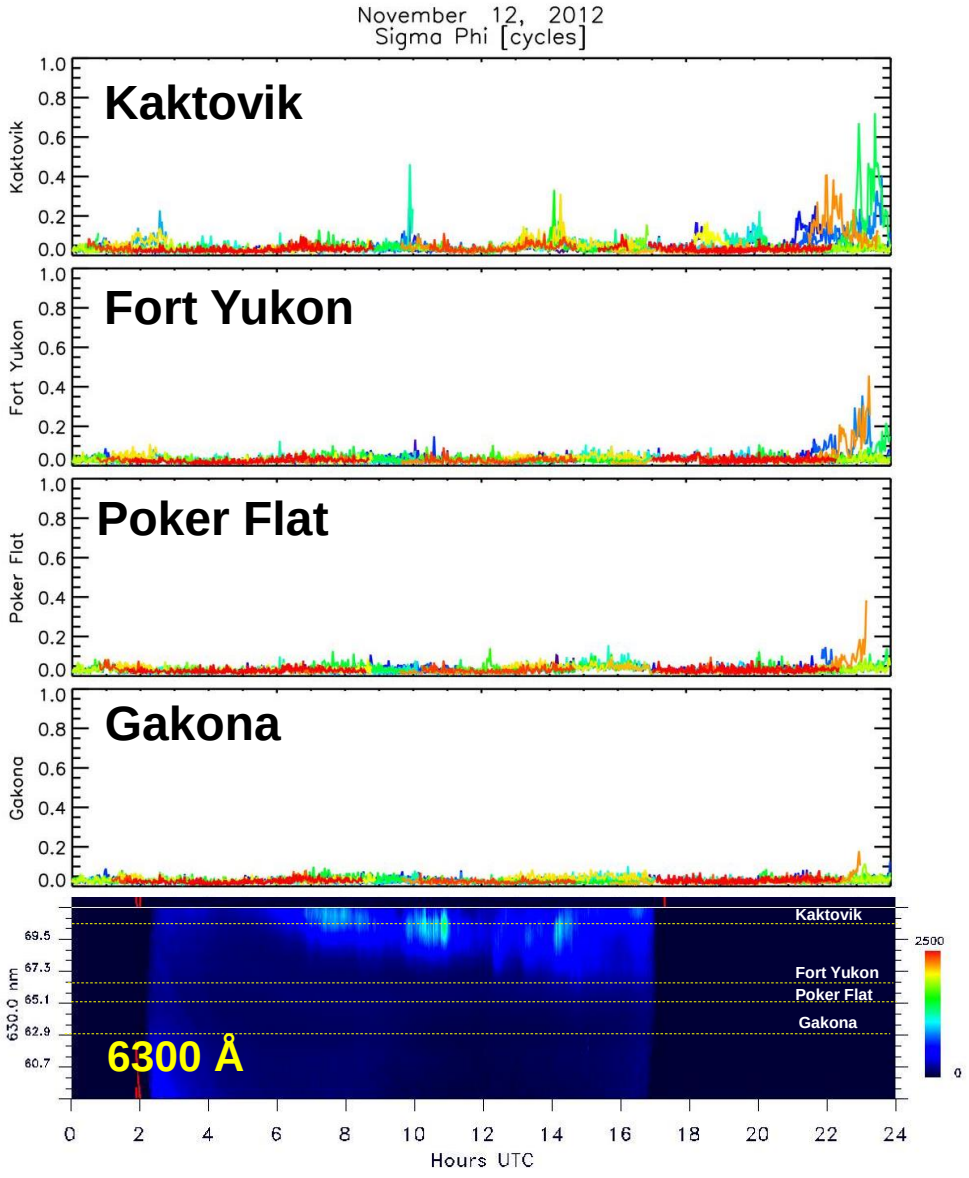

Poker Allsky, 630.0 nm, 14 Nov. 2012
UTC: 04:42:52.18
4
17
20
31
32
23
1
1.0
0.8
0.6
0.4
0.2
0.0

November 12, 2012



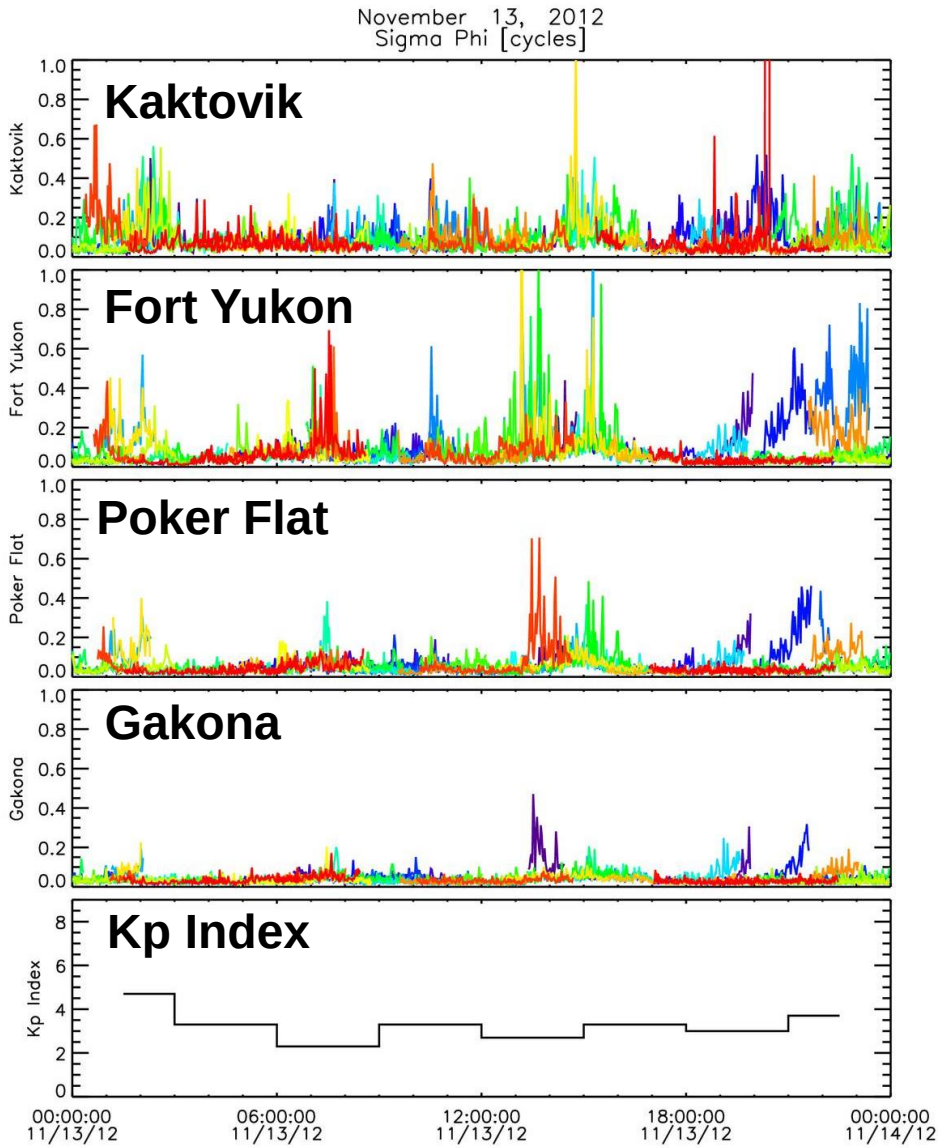
- Each color indicates a different PRN
- Elevation mask of 20° is used
- Kp index was low for majority of the time and increased only moderately after 2100 UT
- Increased phase scintillation at Kaktovik, Fort Yukon, and Poker Flat after 2100 UT

November 12, 2012



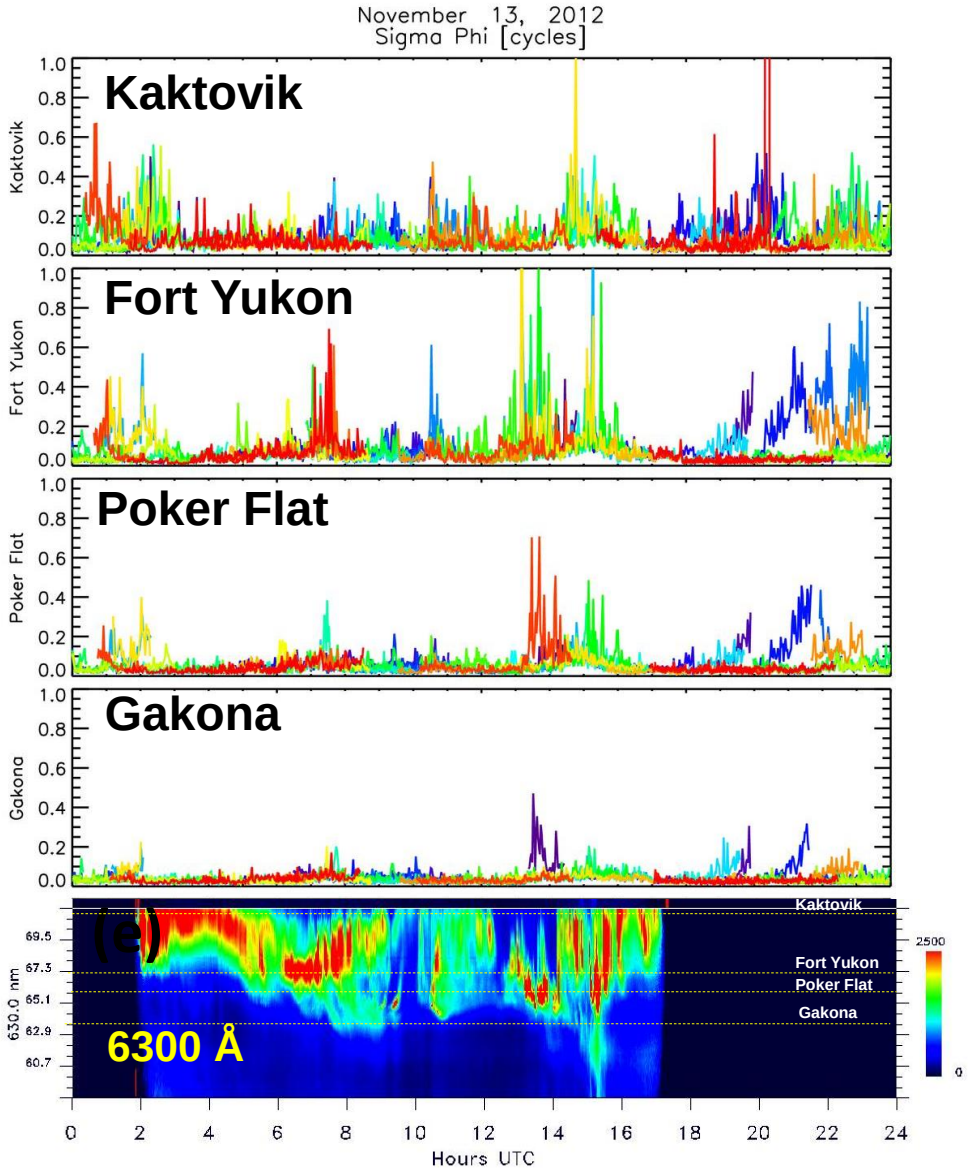
- **Two scintillation events observed in Kaktovik data (at 1000 UT and 1400 UT)**
- **Enhancements in sigma_phi appears to be associated with the brightening of red line auroral emission**
- **Locations south of Kaktovik show no significant auroral activity and no scintillations**

November 13, 2012



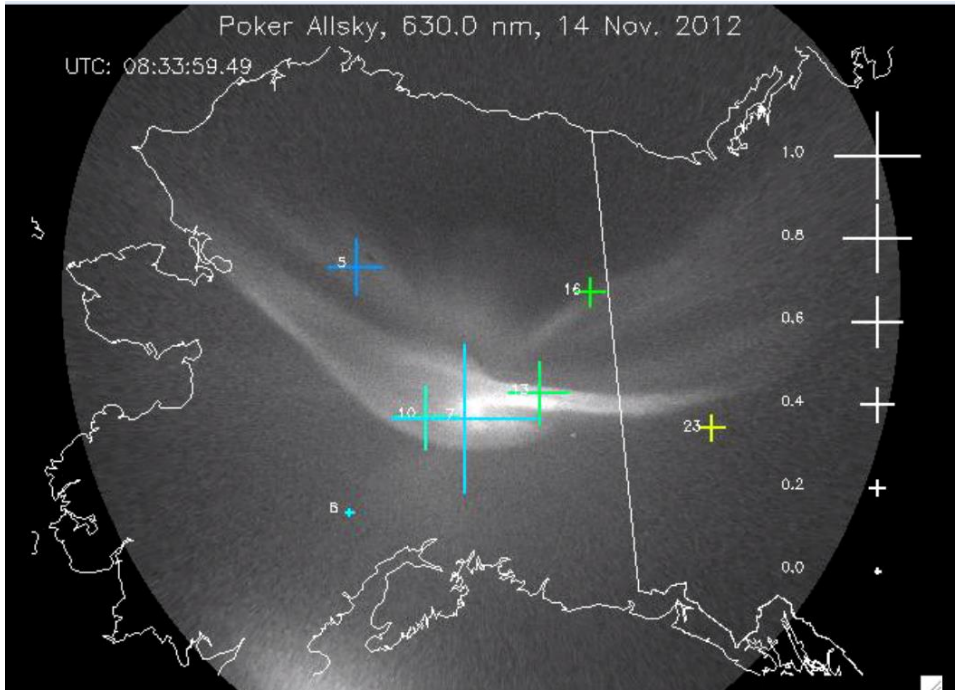
- **November 13, 2012.**
- **Kp = 3+**
- **Scintillation strength decreases south of Kaktovik**

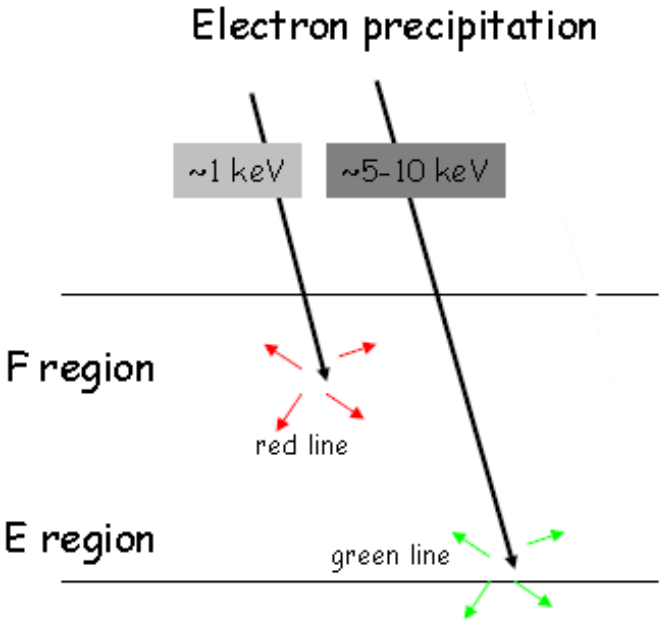
November 13, 2012



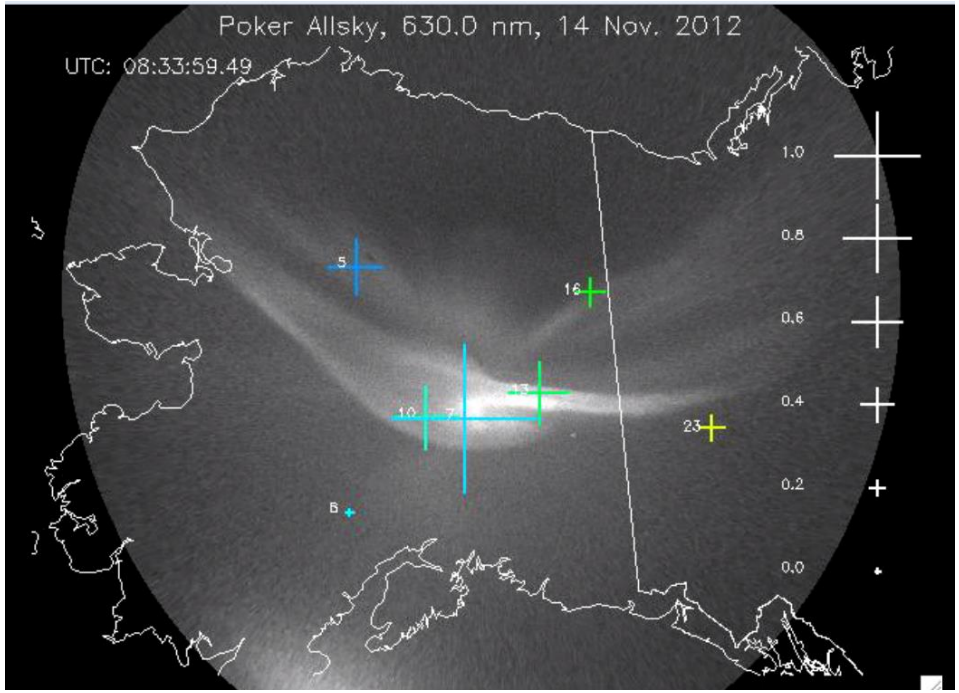
- **Auroral activity was located poleward of Poker Flat (65.1° N) and most of the moderate phase scintillation values were also seen at or poleward of Poker Flat.**
- **At 1300 UT the aurora drifted towards lower latitudes with the equatorward edge of the aurora extending to latitudes near Gakona.**
- **The phase scintillation data from the Gakona site also show increased scintillation during this period characterized by the auroral equatorward transition.**

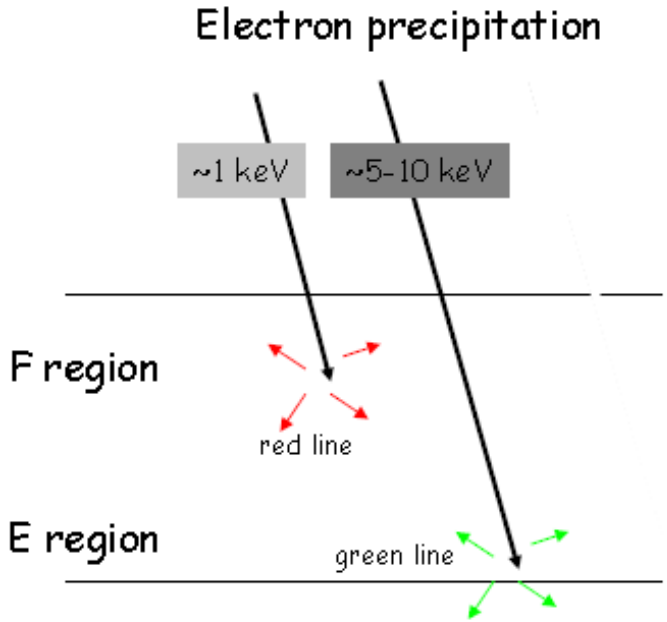
What Causes Scintillation?





What Causes Scintillation?

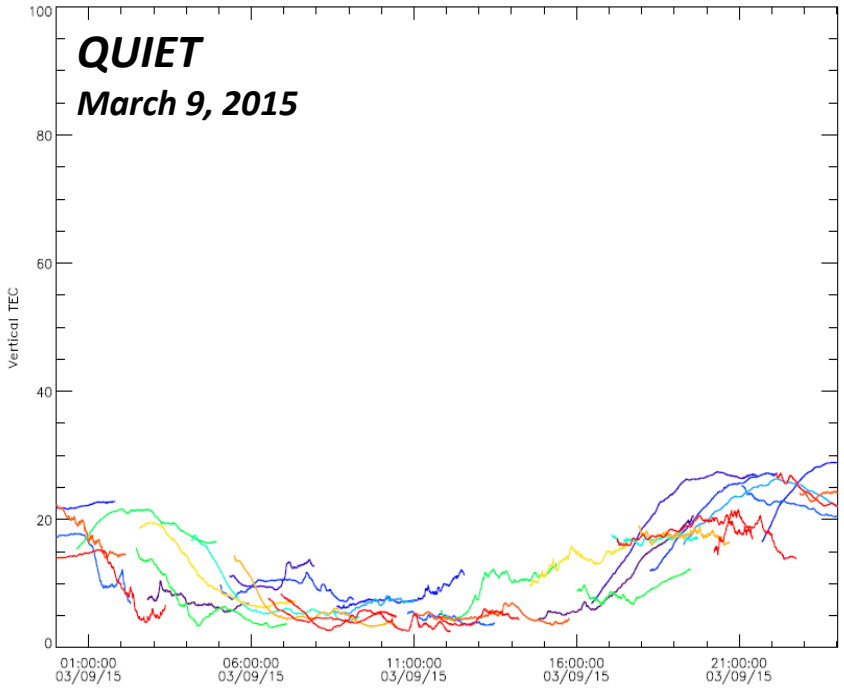


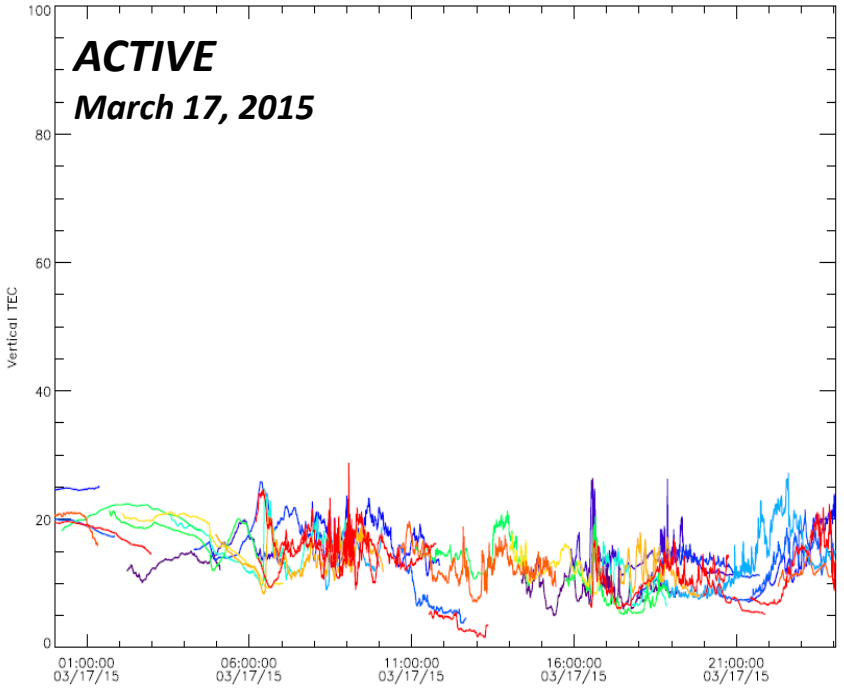


Causes of high latitude ionospheric scintillation not well understood

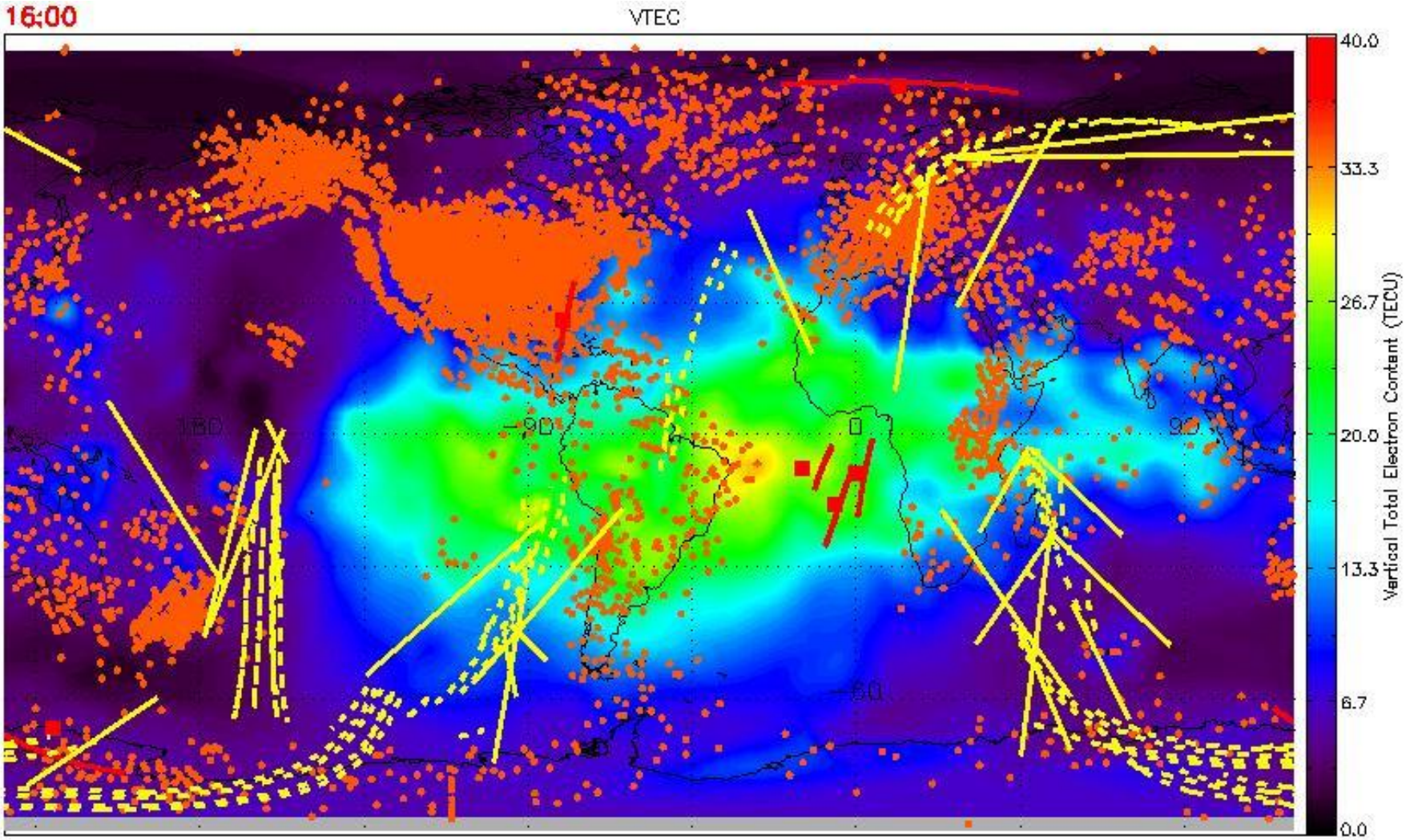
- **E-region structures due to 'hard' particle precipitation**
- **F-region structures due to 'soft' particle precipitation?**
- **F-region structures (patches) moving rapidly?**
- **Gradient drift instability (on edges of F-region structures)?**

Total Electron Content (TEC)





Ionospheric Assimilation



IDA4D Assimilation Model TEC

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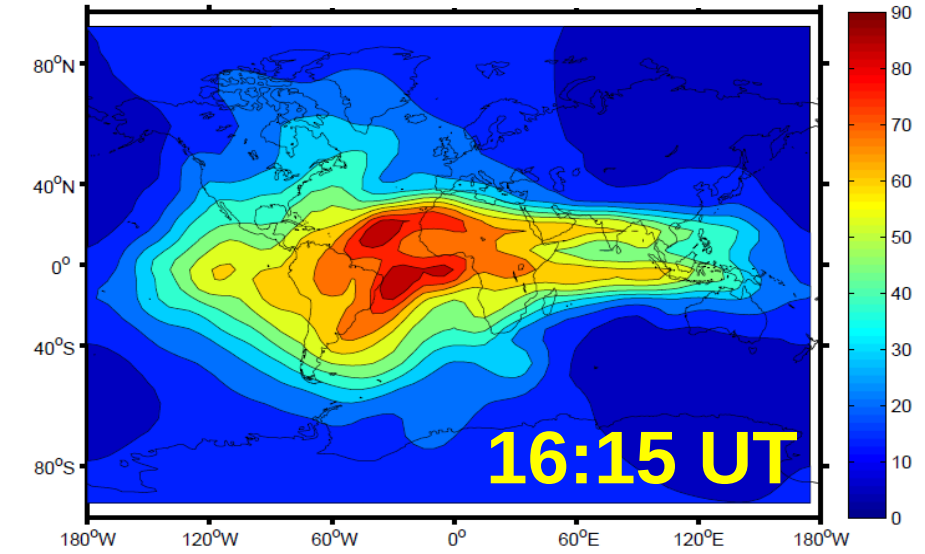
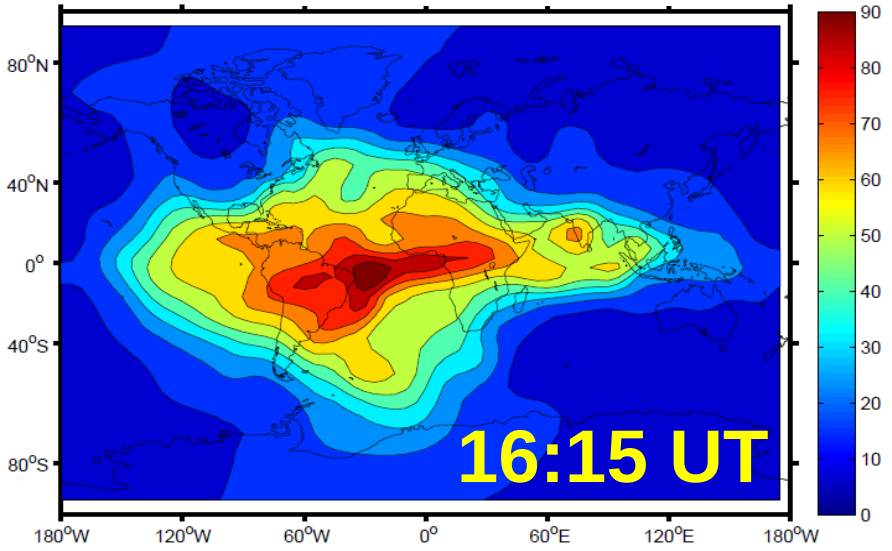
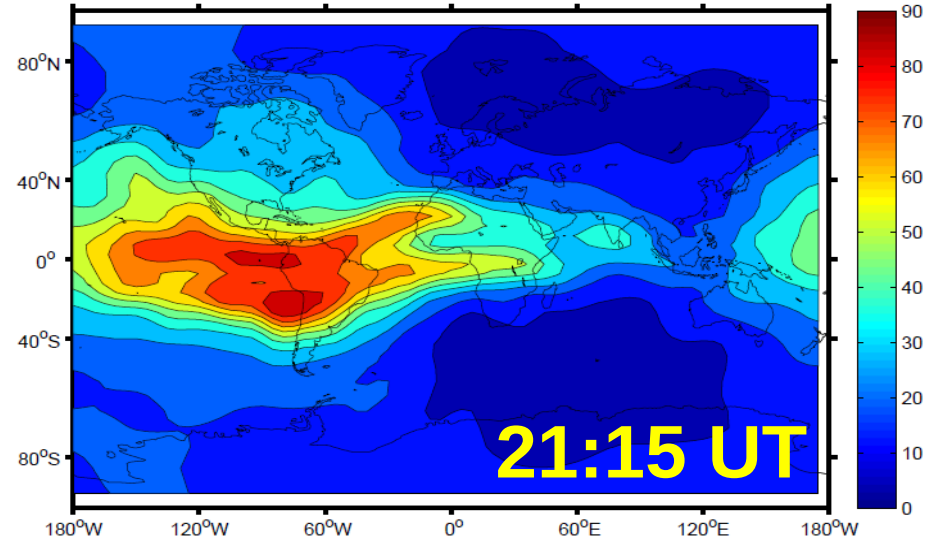
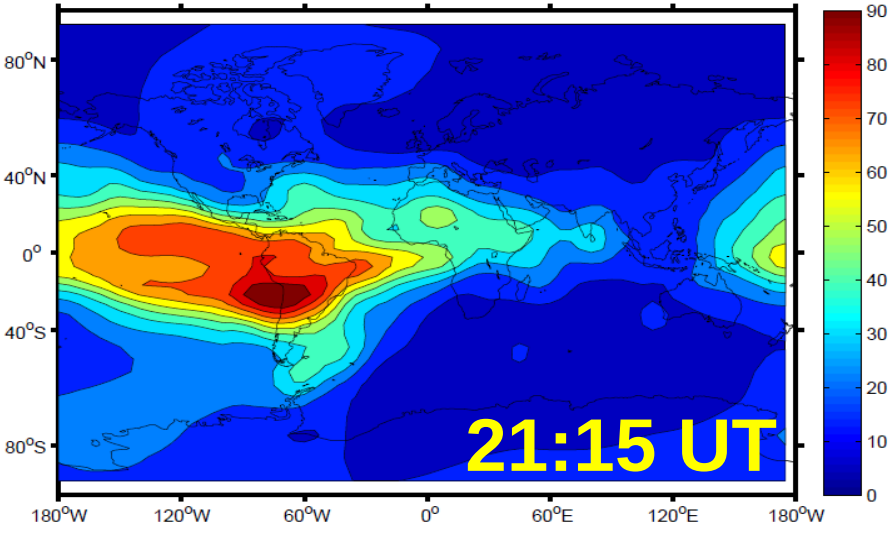
TEC: March 9, 2015



TEC: March 17, 2015







IDA4D Assimilation Model TEC

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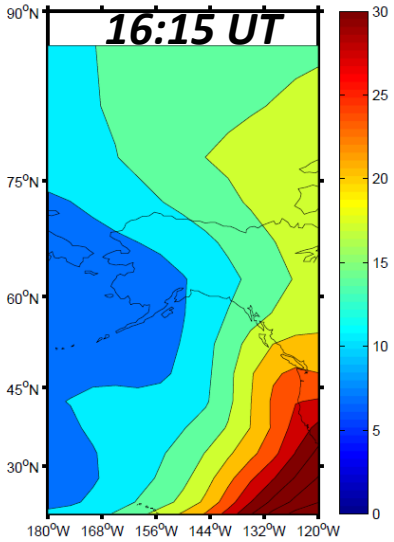

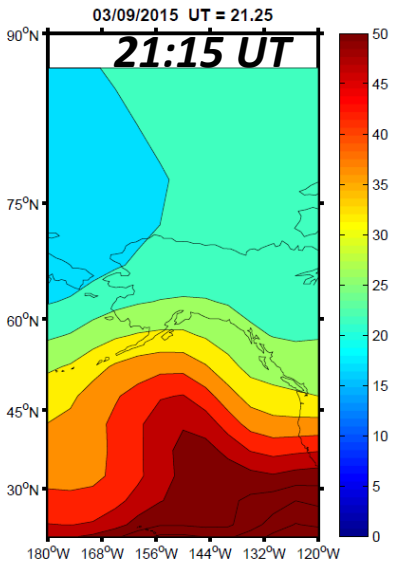

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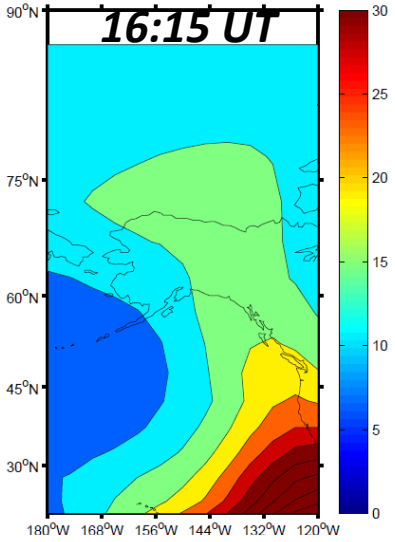

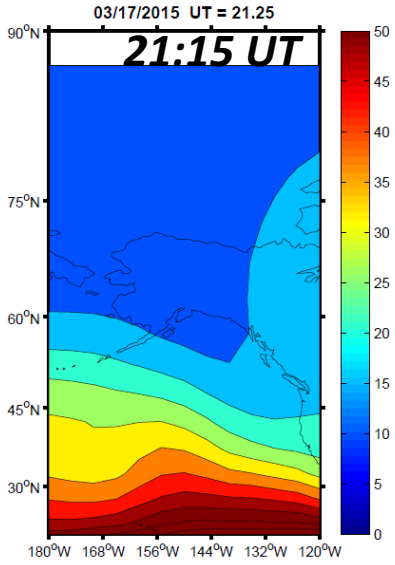

Ionospheric Monitoring from an ocean platform

❖Science
❖ Technology
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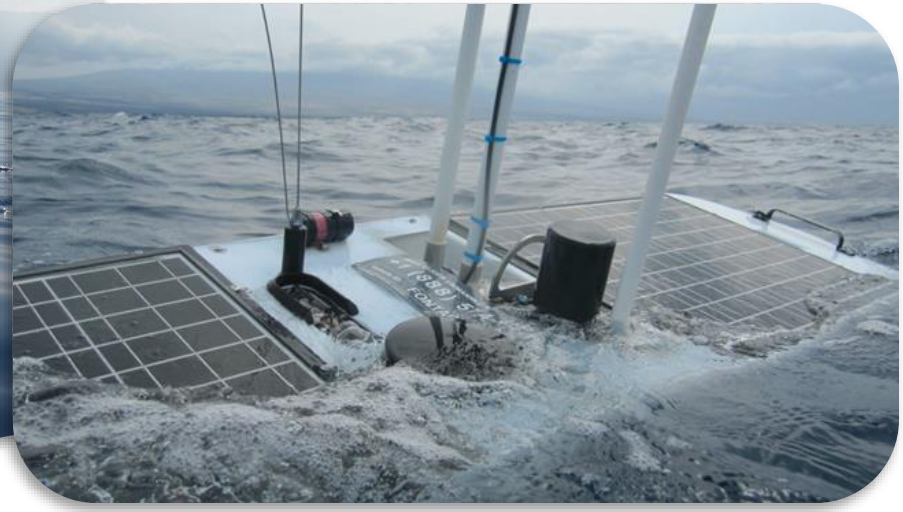
Bringing It All Together

ASTRA

"No one else in the World has done this…"
– recent quote from Technical Director of a multi-Billion dollar International Commercial Services company that provides marine data services

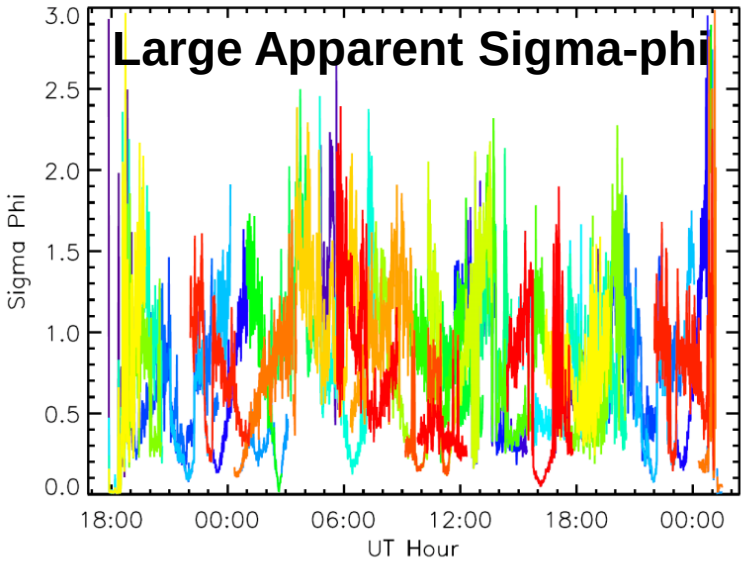


- Near real-time space situational awareness from moving platform
- TEC, scintillation data products, and system's heath status
- Ground link via Iridium or cell towers
- Programmable data latency (Nominal 5 minutes)
- Successful operation in Hawaii, Peru and Australia

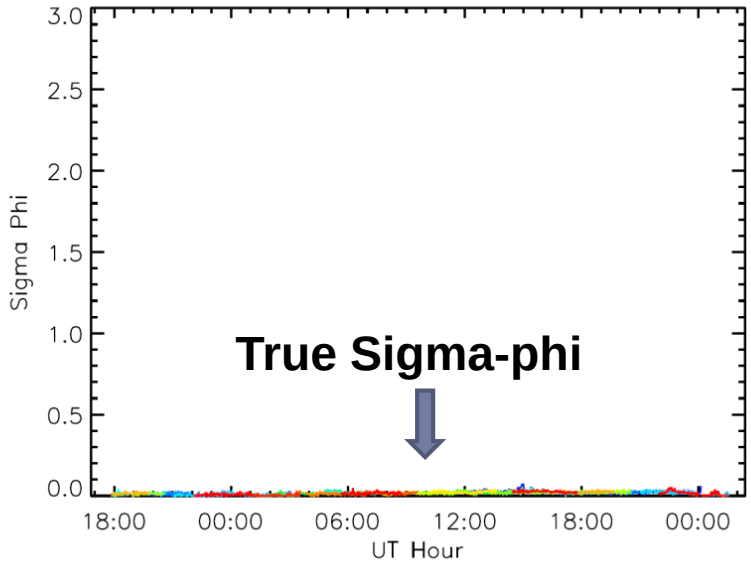
Removing Effects of Motion

- **GPS measurements of ionospheric TEC and scintillation from moving platforms, such as ocean buoys, are extremely challenging**
- **Motion creates large phase variations that look like phase scintillation (left)**
- **ASTRA has overcome this significant problem and can measure real scintillation from a moving platform (see corrected True values on right)**

Without Motion Correction



With Motion Correction



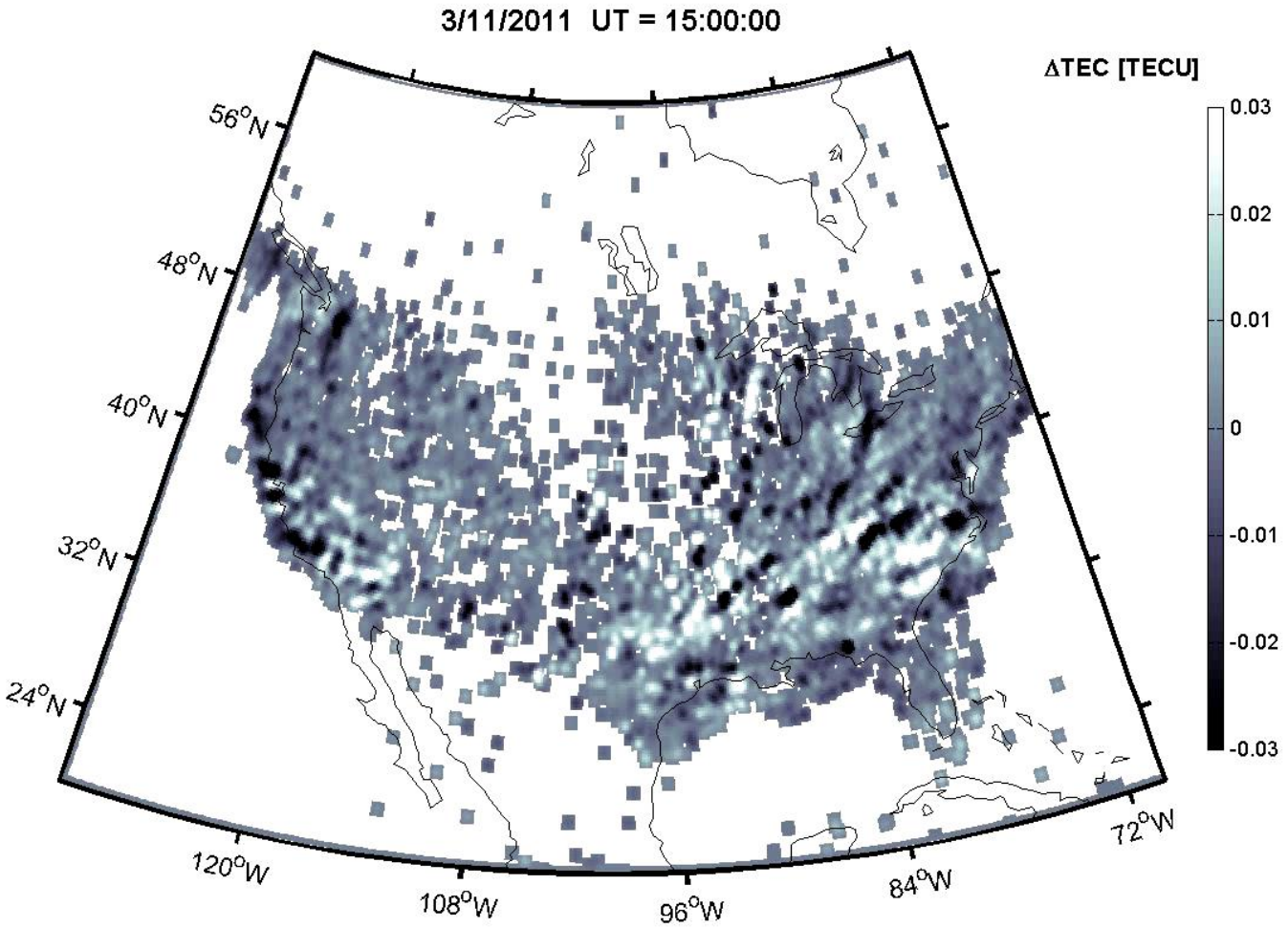
GPS Mapping of Ionosphere

Traveling Ionospheric Disturbances (TIDs)

Sources:

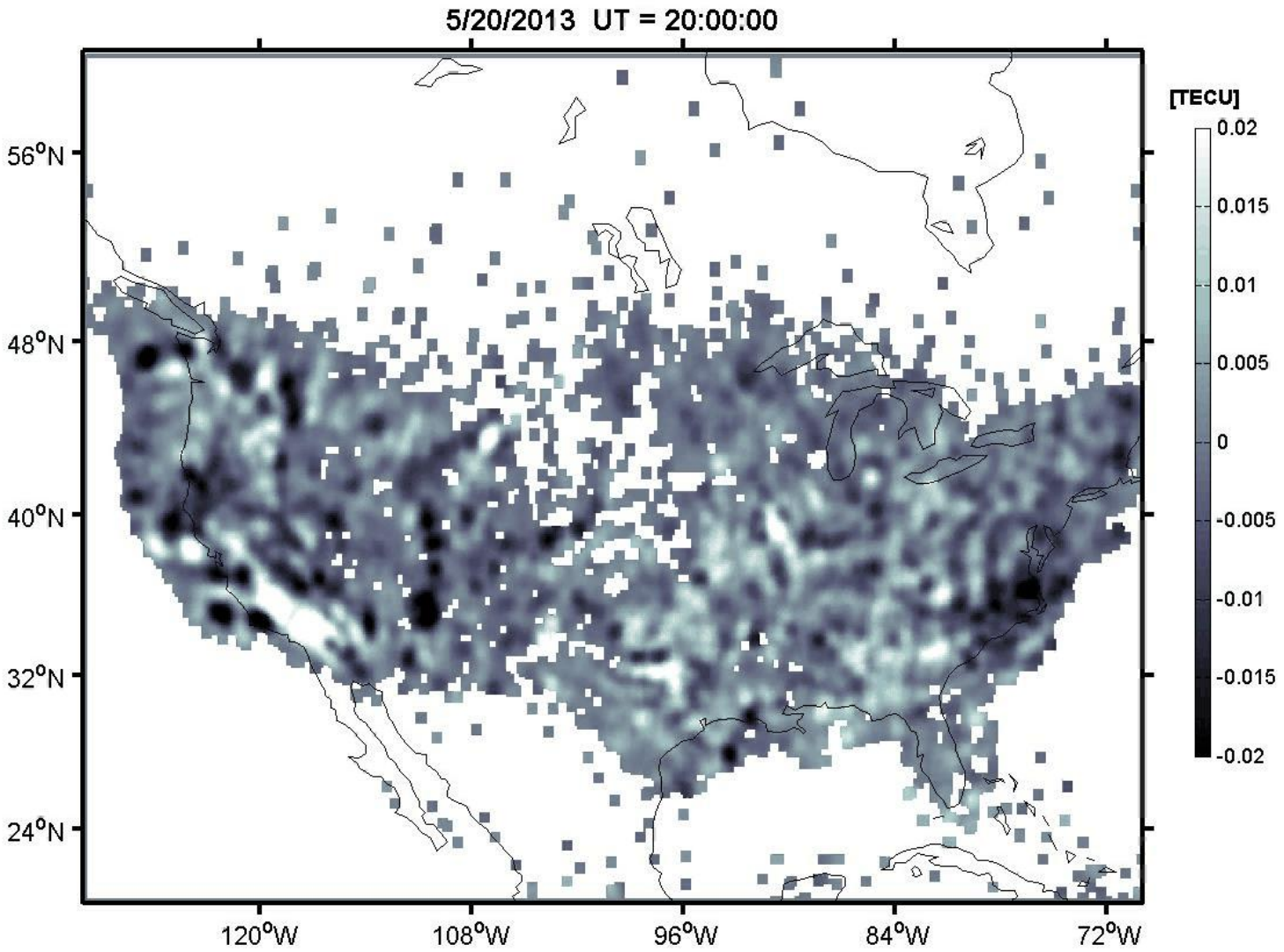
- Ocean waves (and tsunamis)
- Lower atmosphere (thunderstorms, fronts)
- Auroral processes

Tsunami TIDs



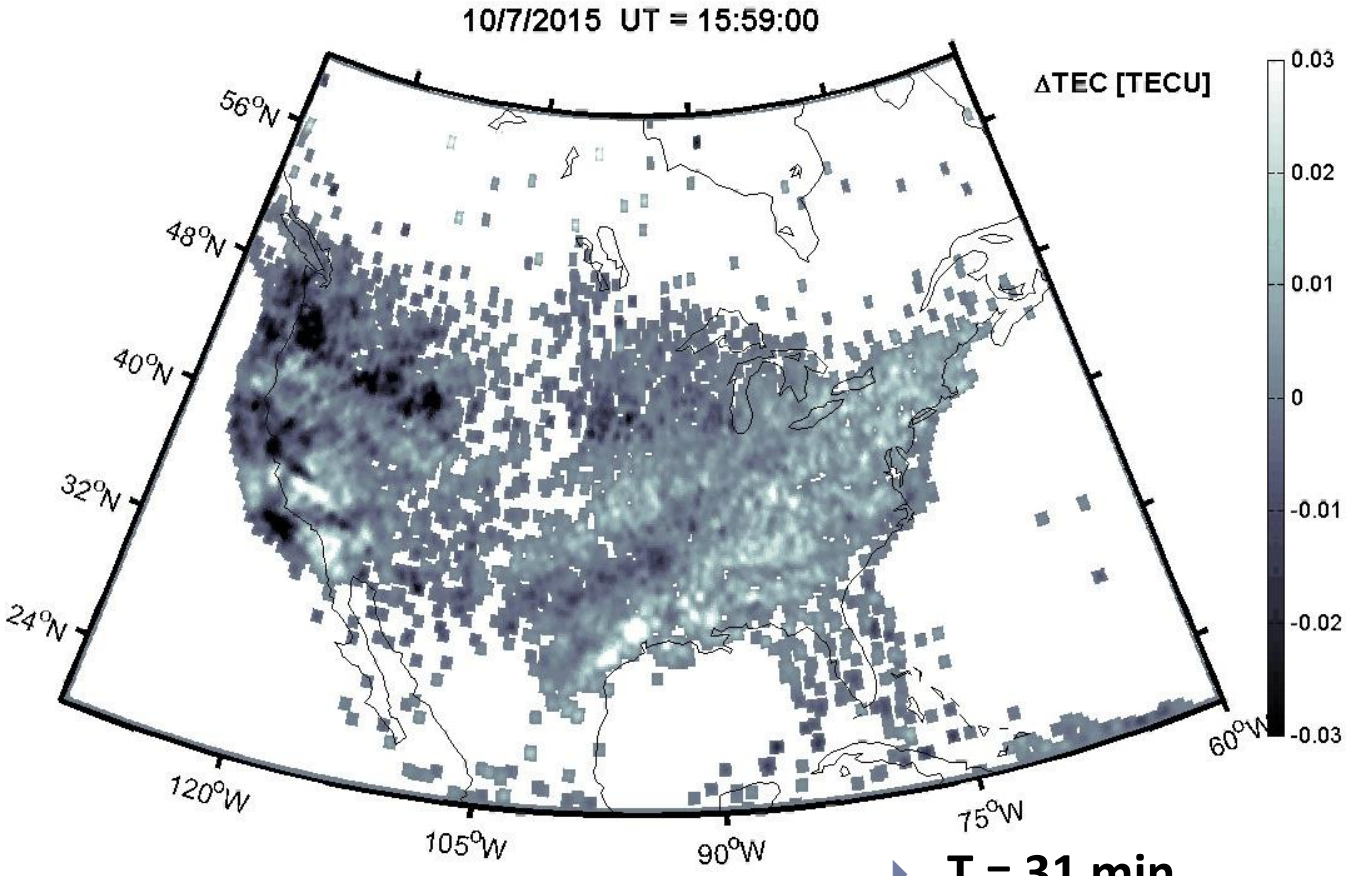
iazeem@astraspace.net 02-Jul-2015 2:41 PM

Thunderstorm TIDs



iazeem@astraspace.net 23-Jun-2015 11:06 AM

Geomagnetic Storm TIDs



- T = 31 min
- vp ~ 390 m/s
- λh ~ 1300 km
- θ = -85 degree

Summary and Conclusions

- Six CASES SM-211 GPS receivers deployed in Alaska
- *Severity of phase scintillation decreases with decreasing latitude.*
- *Largest phase scintillations occur near magnetic midnight.*
- We hypothesize that energetic particle precipitation on the night-side might be responsible for the irregularities associated with these phase scintillation events.
- Future studies will investigate this hypothesis with additional radar data on ionospheric irregularities and particle precipitation.
- Demonstrates our ability to map scintillation in real-time, and to provide space weather services to GPS users.

- Demonstrated GPS monitoring from ocean-buoys
- TEC from 4000 US stations enables mapping of TIDs
- Importance of coupling from below (esp. during solar minimum)